CMS Phase 2 Projects

Andrews-02 (2012)

Project Title: North American Regional-Scale Flux Estimation and Observing System Design for the NASA Carbon Monitoring System

Science Team Members:
Arlyn Andrews, NOAA ESRL (**Project Lead**)
Elena Novakovskaia, Earth Networks, Inc.

Abstract: We propose to apply a high-resolution regional inverse modeling framework to quantify CO2 fluxes that are optimally consistent with surface, aircraft, and satellite data, both current and planned. We will develop objective metrics for weighting the data and use a Lagrangian atmospheric transport model to compute a library of footprints corresponding to the various sources of CO2 observations. We will investigate consistency among the available datasets, taking into account uncertainties caused by satellite retrieval errors and model inadequacies, such as errors in simulated atmospheric transport and structural and numerical limitations of current inversion approaches (particularly when applied to the large volume of satellite data). This work fosters collaboration between Federal agencies, academia, and private industry engaged in greenhouse gas research and monitoring and leverages multiple NASA- and USGCRP-funded efforts to obtain measurements of atmospheric CO2 and develop regional-scale inverse modeling tools for quantifying carbon dioxide fluxes and their uncertainties. The proposed work will inform the development of the NASA Carbon Monitoring System (CMS) Flux Product, in particular regarding strategies for incorporating diverse CO2 observations and quantifying fluxes at policy-relevant scales. The proposed data products will be directly useful for evaluating the current CMS Flux Product.

Keywords:

Project Associations:

- NASA CMS

Spatial Extents of Study:

- US

CMS:

- Atmospheric Transport
- Land-Atmosphere Flux

Participants:
Arlyn Andrews, NOAA ESRL
Anna Michalak, Carnegie Inst. for Science
Elena Novakovskaia, Earth Networks, Inc.

Project URL(s): None provided.

Research Contributions:

Contribution	**Available by:**
Product Title: 1) Species independent sampling footprints and trajectories for aircraft, surface and satellite data, 2) CO2 flux estimates, 3) Estimated CO2 profiles corresponding to GOSAT XCO2 observations	

Description:

- **Objective:** Use in situ observations and remote sensing data (ACOS GOSAT + TCCON) together in a regional inverse modeling framework for North America. Comapre with CMS flux estimates.
- **Inputs/Data products used:** ACOS/GOSAT, NOAA surface and aircraft obserbations, Environment Canada surface CO2, Earth Networks CO2, Penn State / Ameriflux CO2, NCAR RACCOON CO2, TCCON CO2
- **Algorithm/Name of models used:** STILT-WRF, HYSPLIT-HRRR, Gostatistical Inverse Modeling

(GIM)

- **Spatial Domain:** North America
- **Time Period:** July 2009 - December 2010
- **Evaluation:** multiple trsnport models, GOSAT, surface and aircraft netwiork
- **Intercomparison efforts/gaps:** 1) comparison of best estimate CO2 profiles with ACOS GOSAT data, 2) evaluation of posterior fluxes using surface and aircraft data, 3) comparison of best estimate fluxes with CMS-FPP and NOAA CarbonTracker fluxes
- **Uncertainty estimates:** 1) case study with two separate transport models (STILT-WRF vs HYSPLIT-HRRR), 2) bayesian versus geostatistical inverse modeling, 3) tests of alternative data-weighting and inclusion/exclusion of certain datasets
- **Uncertainty categories:** All: ensemble; deterministic; model-data comparison; model-model comparison; data-data comparison

Expected Users:
Metadata URL(s):
Data Server URL(s):

Publications: None provided.

Balch-03 (2012)

Project Title: Coccolithophores of the Beaufort and Chukchi Seas: Harbingers of a polar biogeochemical province in transition?

Science Team Members: William (Barney) Balch, Bigelow Laboratory for Ocean Sciences (**Project Lead**)

Abstract: I propose a series of biological and bio-optical observations to address the role of calcifiers in the Arctic Ocean (AO). The biogeochemical province that includes the Chukchi and Beaufort Seas is expected to undergo fundamental changes as the ice cap melts, affecting both the biota (increased abundance of coccolithophores) and the biooptical properties of the water mass (due to increased abundance of highly-scattering calcium carbonate coccoliths). I am proposing a series of measurements to be done on the two NASA cruises to the Chukchi and Beaufort Seas, falling into “discrete” and “underway” sampling. The discrete measurements will determine: calcification rate (using the 14C micro-diffusion method which also estimates total primary productivity), concentrations of the two major sea water ballast minerals (particulate inorganic carbon (PIC) plus biogenic silica (BSi)) and coccolithophore/phytoplankton abundance (using polarized microscopy plus a Flow-cam). Automated underway measurements will be made for: inherent optical properties (spectral absorption and attenuation [dissolved and particulate], backscattering, acid-labile backscattering, chlorophyll fluorescence, all sampled from the ship’s seawater system) plus apparent optical properties (spectral upwelling radiance, sky radiance and downwelling irradiance as measured from bowmounted radiometers). The latter measurements will provide critical matchups for satellite measurements, as well as radiometry for use in real time estimates of chlorophyll and PIC when clouds obscure the satellite view. In the latter two years of the project, the ship data will be used for regional calibration and validation of PIC and calcification algorithms so that we can use the historical data base of satellite ocean color to examine for long-term changes in coccolithophore abundance in the AO. This work will provide fundamental, new knowledge on the standing stocks and production rates of calcium carbonate

by coccolithophores, in the Chukchi and Beaufort Seas. These proposed measurements will be the first-ever, direct 14C measurements of coccolithophore calcification in the AO, as opposed to indirect estimates based on carbonate system parameters or ocean color. Why is this important? First, PIC represents the most important ballast material responsible for sinking POC, which drives the biological pump. Indeed, the future of calcification and PIC production represents the future of the ocean's biological pump. Moreover, even at typical, non-bloom concentrations, coccolith PIC is a significant contributor to the ocean albedo. In summer, they likely have even greater impact in the AO when extensive coccolithophore blooms form. Second, global climate change and ocean acidification are bringing unprecedented changes to the AO by a) melting the seasonal plus permanent sea ice cover, and b) slowly decreasing the pH over the next century. Decreasing sea ice cover will likely bring about a major biological shift in the Boreal Polar biogeochemical province (Longhurst et al., 1995), making it more Sub-Arctic in character. This is hypothesized to be allowing the current invasion of coccolithophores to the AO over the last decade. Less sea ice cover may also allow more air-sea influx of anthropogenic CO2, the cause of ocean acidification; this is expected to have the largest negative impact on calcifiers at high latitudes due to lower calcite and aragonite saturation states there. Our bio-optical measurements will allow critical revisions to PIC and calcification algorithms for the AO, technically impossible to do now due to a paucity of ship data. Armed with these validated algorithms, our proposed retrospective investigation of ocean color imagery for PIC and calcification in the AO will be critical to discern long time-scale changes in AO calcifiers associated with climate change.

Keywords:

Project Associations:

- NASA CMS

Spatial Extents of Study:

- US

CMS:

- Ocean Biomass
- Ocean-Atmosphere Flux

Participants: William (Barney) Balch, Bigelow Laboratory for Ocean Sciences

Project URL(s): None provided.

Research Contributions:

Contribution	Available by:
Product Title: A series of biological and bio-optical observations to address the role of calcifiers in the Arctic Ocean (AO)	
Description:	
Expected Users:	
Metadata URL(s):	
Data Server URL(s):	
Site(s) of Data Collection: 68.70000,-172.30000; 71.70000,-137.30000	

[view google map]

Publications: None provided.

Behrenfeld-01 (2012)

Project Title: Characterizing the Phytoplankton Component of Oceanic Particle Assemblages

Science Team Members: Michael Behrenfeld, Oregon State University (**Project Lead**)

Abstract:

This research project is focused on the development of a technique for routinely assessing phytoplankton carbon biomass (Cphyto) in the field. If successful, this investment will create a foundation for (1) evaluating and evolving new satellite Cphyto products, (2) characterizing light- and nutrient-stress effects in the field independently of radiotracer measurements, and (3) distinguishing physiological- and biomass-responses to climate forcings in satellite time-series of ocean color (Fig. 1). The measurement and future validated retrieval of phytoplantkon biomass is essential for understanding global ocean carbon pools and fluxes and for detecting changes in this key carbon stock over time. Throughout the history of satellite ocean color measurements, chlorophyll concentration has functioned as the primary parameter retrieved from space related to the abundance of phytoplankton in the upper ocean. The relationship between phytoplankton biomass and chlorophyll concentration, however, is highly variable due to physiological adjustments in intracellular pigmentation resulting from variations in light and nutrient conditions of the mixed layer. Indeed, phytoplankton Chl:C ratios can vary by nearly 2 orders of magnitude (Geider 1987, Behrenfeld et al. 2005). Recently, an approach has emerged for directly estimating Cphyto from remote sensing retrievals of particle backscattering (Behrenfeld et al. 2005). Multiple studies have attempted to evaluate the scattering-biomass relationship, but true validation of satellite Cphyto products remains impossible due to a near complete lack of field Cphyto estimates. The current proposed study will develop a technique for measuring Cphyto and demonstrate its application in the field. Our approach is multifaceted to improve the probability of success, including both flow-cytometer sample analysis and construction of a new liquid-aperture particle counter/sizer. This work directly addresses the objectives of NASA's Ocean Biology and Biogeochemistry program by providing new scientific evaluation capabilities for novel space-based measurements of global ocean phytoplankton communities that will improve ocean productivity estimates and lead to robust satellite physiological products for comparison with ocean biogeochemical-ecosystem models.

Keywords:

Measurement Approaches:

- Remote Sensing
- In Situ Measurements

Project Associations:

- NASA CMS

Spatial Extents of Study:

- Oceans
- US

CMS:

- Ocean Biomass

Participants:

Michael Behrenfeld, Oregon State University
Jason Graff, Oregon State University
Allen Milligan, Oregon Sate University

Project URL(s): None provided.

Research Contributions:

Contribution	**Available by:**
Product Title: Measurements of phytoplankton carbon	

Description:

- **Objective:** Develop method(s) for measuring phytoplankton carbon biomass in the open ocean on a routine basis
- **Inputs/Data products used:**
- **Algorithm/Name of models used:** N/A for this study directly, but is relevant to the Carbon-based Production Model (CbPM)
- **Spatial Domain:** global

- **Time Period:** 1997 - present
- **Evaluation:**
- **Intercomparison efforts/gaps:** site specific comparision to local optical measurements
- **Uncertainty estimates:** preliminary evaluation of uncertainty can be made with point-source data but full evaluation of global phytoplankton carbon retrieval uncertainties is beyond the scope of current study and must await additional funding.
- **Uncertainty categories:** model-data comparison

Expected Users:

Metadata URL(s):

Data Server URL(s):

Publications: Graff,J.R., A.J. Milligan, M.J. Behrenfeld (2012) The measurement of phytoplankton biomass using flow-cytometric sorting and elemental analysis of carbon. Limnol. Oceanogr. Meth. 10: 910-920. doi: 10.4319/lom.2012.10.910

Bowman-01 (2012)

Project Title: Continuation of the Carbon Monitoring System Flux Pilot Project

Science Team Members:
Kevin Bowman, JPL (**Project Lead**)
Holger Brix, UCLA
Scott Denning, Colorado State University
Christian Frankenberg, Jet Propulsion Laboratory / Caltech
Kevin Gurney, Arizona State University
Daven Henze, CU
Christopher (Chris) Hill, MIT
Meemong Lee, JPL
Junjie Liu, JPL
Eric Marland, Appalachian State University
Dimitris Menemenlis, JPL

Abstract: We propose to evolve the Carbon Monitoring System Flux Pilot Project funded under Phase 1 into a framework that integrates observational constraints on all major components of the carbon-cycle-anthropogenic system anthropogenic, terrestrial, oceanic, atmospheric in a top-down CO2 attribution system constrained by atmospheric satellite observations. This expanded framework will enable a deeper understanding of the global carbon cycle and a means of quantifying the effectiveness of climate mitigation policies. This CMS-FPP is motivated by the increase in tropospheric CO2 from anthropogenic emissions, which is the single largest driver of observed and predicted climate change [Forster et al, 2007]. However, roughly half of the CO2 produced from these emissions has been removed by terrestrial and ocean sinks. Consequently, The future trajectory of climate forcing will depend on future emissions and on the capacity of the carbon-cycle to absorb more CO2 [Friedlingstein, 2008]. Recent years have seen an acceleration of fossil fuel emissions and signs of an onset of carbon-cycle feedbacks [Canadell et al, 2007]. Since 2005, fossil fuel emissions have been regionally redistributed towards developing countries, which now make up more than half of CO2 emissions (>4 PgC/yr) [Peters et al, 2012]. While the global carbon budget and its partitioning between anthropogenic, terrestrial, and oceanic fluxes are reasonably understood, the contribution of regional drivers to that budget are not [Canadell et al, 2010]. Consequently, uncertainty in the attribution of CO2 accumulation rate on a year-to-year basis to those drivers limits our capacity to quantify the effectiveness of climate mitigation policies [Le Quere et al, 2009]. In order to reduce uncertainty in CO2

attribution, we will simultaneously improve and augment all major aspects of the current CMS-FPP: new satellites observations, an additional terrestrial eco-system model, a new fossil fuel assimilation system, updated ocean assimilation algorithms, and improved atmospheric inversion algorithms. The CMS-FPP Phase 2 will generate a suite of new and updated products covering 7/2009- 2011 including new global spatially resolved CO2 sources and sinks, new high resolution global fossil fuel emissions, better estimates of oceanic CO2 air-sea exchange, new estimates of global above-ground biomass, and refinements in top-down attribution and uncertainty algorithms. Products generated from bottom-up and top-down estimates will be made publically available through carbon.nasa.gov and linked to cmsflux.jpl.nasa.gov. Through these updates, the CMS-FPP will play a crucial and on-going role in assessing the current capability of space-borne observing systems to improve our knowledge of the integrated carbon-cycle-anthropogenic system and its impact on climate forcing

Keywords:

Project Associations:

- NASA CMS

Spatial Extents of Study:

- US

CMS:

- Land-Atmosphere Flux
- Ocean-Atmosphere Flux
- Global Flux

Participants:

Salvi AsefiNajafabady, Arizona State University, School of Life Sciences
Christopher Badurek, Appalachian State University
Nicolas Bousserez, University of Colorado
Kevin Bowman, JPL
Holger Brix, UCLA
Scott Denning, Colorado State University
Christian Frankenberg, Jet Propulsion Laboratory / Caltech
Kevin Gurney, Arizona State University
Daven Henze, CU
Christopher (Chris) Hill, MIT
Maya Hutchins, Appalachian State University
Meemong Lee, JPL
Junjie Liu, JPL
Eric Marland, Appalachian State University
Dimitris Menemenlis, JPL
John Worden, JPL

Project URL(s):

http://cmsflux.jpl.nasa.gov
http://ecco2.org

Research Contributions:

Contribution	**Available by:**
Product Title: Terrestrial biosphere flux constrainded by observations and their uncertainties	
Description: • **Objective:** Atmospheric top-down flux inversion. • **Inputs/Data products used:** ACOS-GOSAT Xco2 observatioins; flux inventories from fossil fuel emissioins, fire emissions, air-sea fluxes, terrestrial biosphere flux • **Algorithm/Name of models used:** GEOS-Chem	

- **Spatial Domain:** Global
- **Time Period:** 2009-2011
- **Evaluation:** surface and aircraft sampling network, TCCON
- **Intercomparison efforts/gaps:**
- **Uncertainty estimates:** The following is how we categorize the uncertainty in the flux estimation from atmospheric top-down flux inversion. Currently, we use both Monte Carlo approach and formal numerical uncertainty quantification extracted from numerical minimization algorithm (Nicolas Bousserez). In the Monte Carlo approach, we sample the uncertainty of both the a priori flux and observations, and then the standard deviation of the Monte Carlo flux estimations gives the uncertainty estimation. The uncertainty of the a priori flux is from the model-model comparison (e.g., different biospheric models), and the observation uncertainty is from the product. In addition, we also investigate the sensitivity of the flux estimation for one category of flux (e.g., biosphere flux) to the uncertainty of the prescribed flux (e.g., Fossil fuel).
- **Uncertainty categories:** deterministic and ensemble

Expected Users:

Metadata URL(s):

Data Server URL(s):
cmsflux.jpl.nasa.gov

Contribution	**Available by:**

Product Title: CO2 flux

Description:

- **Objective:** 4D-Var inversion uncertainty quantification
- **Inputs/Data products used:** GOSAT xCO2
- **Algorithm/Name of models used:** GEOS-Chem
- **Spatial Domain:** Global
- **Time Period:** 2009-2011
- **Evaluation:**
- **Intercomparison efforts/gaps:**
- **Uncertainty estimates:** Two approaches:1)stochastic: Monte-Carlo (Junjie Liu), gradient-based randomization, 2)deterministic: using the BFGS inverse Hessian approximation
- **Uncertainty categories:** deterministic and ensemble

Expected Users:	
Metadata URL(s):	
Data Server URL(s):	

Contribution	**Available by:**
Product Title: air-sea CO2 flux (& time-evolving ocean physics, ecology, and biogeochemistry)	

Description:

- **Objective:** Provide estimates of ocean surface carbon dioxide flluxes.
- **Inputs/Data products used:**
- **Algorithm/Name of models used:** ECCO2-Darwin configuration of MITgcm
- **Spatial Domain:** global
- **Time Period:** 2009-2011
- **Evaluation:**
- **Intercomparison efforts/gaps:**
- **Uncertainty estimates:** model-data comparison
- **Uncertainty categories:** model-data comparison

Expected Users:	
Metadata URL(s):	
Data Server URL(s):	

Publications: None provided.

4th NACP All-Investigators Meeting Posters:

- Source quantification and geolocation of global power plant emissions using a novel crowd-sourcing system: transfer of knowledge from one decisionmaker group to another -- (Kevin Robert Gurney, *Fionn Darragh O'Keeffe*) [abstract]
- Complementary Constrains on Seasonal Carbon Balance in Amazonia from GOSAT Measurements of XCO2 and Chlorophyll Fluorescence -- (*Nick Parazoo*, Kevin W Bowman, Christian Frankenberg, Jung-Eun Lee, Joshua B. Fisher, John R. Worden, Dylan Jones, Joseph A Berry, George James Collatz, Ian Baker, Martin Jung, Junjie Liu, Gregory Osterman, Christopher O'Dell, Athena Sparks, Andre Butz, Sandrine Guerlet, Yoshida Yukio, Huilin Chen, Christoph Gerbig) [abstract]
- Analysis of interpolation technique and resolution effects on the aggregation of power plant carbon dioxide emissions at state and county scales -- (Maya G. Hutchins, Christopher A. Badurek, *Gregg Marland*, Eric Marland) [abstract]

Cook-B-01 (2012)

Project Title: Improving Forest Biomass Mapping Accuracy with Optical-LiDAR Data and Hierarchical Bayesian Spatial Models

Science Team Members: Bruce Cook, NASA GSFC (**Project Lead**)
Andrew (Andy) Finley, Michigan State University

Abstract: We propose to implement a novel approach for mapping forest biomass and associated errors using the fusion of airborne LiDAR, passive optical and thermal data and a Bayesian hierarchical model that accounts for spatial variances between ground observations and remotely sensed data. This method will be compared with the more traditional approach of using a variety of plot-scale LiDAR metrics in a generalized, multiple linear regression model for relatively large region of interest (e.g., county- or state- scale). Also, we will use fine-resolution LiDAR and passive optical data (<1 m) to delineate individual trees, identify species class, and derive additional tree-level attributes (e.g., crown dimensions, crown area weighted heights, stem density) to improve upon biomass estimates made with aggregated point cloud metrics and inventory data at the plot-level (the traditional approach). These three methods will be evaluated and compared at four study sites in the midAtlantic and New England regions of the eastern US: Howland Forest and Holt Research Forest, ME; Harvard Forest, MA; and the Smithsonian Environmental Research Center near Edgewater, MD. This study will leverage coincident and co-registered LiDAR, passive optical, and thermal data that were collected at these sites for NASA s local-scale biomass pilot project between 2011 and 2012. Remotely sensed data was collected with Goddard s LiDAR, Hyperspectral, and Thermal (G-LiHT) airborne imager, which PI Cook developed at NASA-GSFC for studying the complex relationship between terrestrial ecosystem form and function. Large-area stem maps (3 to 35 ha per site, in which all stems greater than 1 cm have been measured) exist at each of these study sites, and these data will be used to verify crown delineations and enable the creation of a fineresolution spectral library. Subsets of the stem map areas will be used to simulate inventory plots, which will then be used as inputs for the Bayesian spatial latent factor model. Each of the stem map areas contain a variety of over/understory tree species, variable topography and range of drainage conditions, which will allow us to validate each of the methods over a wide range of forest types between and within each of the four study sites. Benefits of the proposed Bayesian spatial latent factor prediction model are 1) variables are selected using an efficient, dimension reduction technique; 2) spatial dependencies are incorporated into the model to and improve inference; 3) data compression is used to reduce the computational burden; and 4) sources of uncertainty are acknowledged and propagated through to prediction. Benefits of using data fusion for biomass mapping is that LiDAR and passive optical data provide unique information on the 3- dimensional structure and species composition of the forest, respectively. This synergy has been the focus of recent research, and has spawned the development of multi-instrument airborne systems such at the Carnegie Airborne Observatory (CAO), NASA s G-LiHT, and National Ecological Observatory Network (NEON) system that will begin systematic data collections in 2012. New algorithms and model variables for mapping forest biomass, such as the Bayesian latent spatial factor model and individual tree attributes we propose in this study, are needed to take full advantage of the synergy offered by these new, complementary datasets.

Keywords:

Measurement Approaches:
- Remote Sensing
- Airborne Sampling
- In Situ Measurements

Science Questions:
- Diagnosis

GHG Compounds:
- Carbon Dioxide

Project Associations:
- NASA CMS

Interim Synthesis:
- Site-Level

Spatial Extents of Study:
- Site
- Subregional Intensive
- US

CMS:
- Land Biomass

Other Keywords: LiDAR

Participants: Bruce Cook, NASA GSFC
Lawrence Corp, Sigma Space
Andrew (Andy) Finley, Michigan State University
Hank Margolis, Laval University
Jamon Van Den Hoek, NASA GSFC

Project URL(s): http://gliht.gsfc.nasa.gov/

Research Contributions: None provided.

Publications:

Huang, Wenli; Sun, Guoqing; Dubayah, Ralph; et al. 2013. Mapping biomass change after forest disturbance: Applying LiDAR footprint-derived models at key map scales. REMOTE SENSING OF ENVIRONMENT 134: 319-332. doi: 10.1016/j.rse.2013.03.017

Finley, A. O., S. Banerjee, B. D. Cook, and J. B. Bradford. 2013. Hierarchical Bayesian spatial models for predicting multiple forest variables using waveform LiDAR, hyperspectral imagery, and large inventory datasets. International Journal of Applied Earth Observation and Geoinformation 22SI: 147-160. doi: 10.1016/j.jag.2012.04.007

Montesano, P. M.; Cook, B. D.; Sun, G.; et al. 2013. Achieving accuracy requirements for forest biomass mapping: A spaceborne data fusion method for estimating forest biomass and LiDAR sampling error. REMOTE SENSING OF ENVIRONMENT 130: 153-170 doi: 10.1016/j.rse.2012.11.016

4th NACP All-Investigators Meeting Posters:

- Examining the Carbon Sequestration Potential of Recently Disturbed Trees in a Managed Northern Wisconsin Forest -- (*Jamon Van Den Hoek*, Bruce Cook, Jeffrey Masek, Robert E Kennedy, Compton Tucker) [abstract] [poster]

Dubayah-03 (2012)

Project Title: High Resolution Carbon Monitoring and Modeling: A CMS Phase 2 Study

Science Team Members: Ralph Dubayah, University of Maryland (**Project Lead**)
George Hurtt, University of Maryland

Abstract: The overall goal of our proposed research is the continuing prototype development of a framework for estimating local-scale carbon stocks and future carbon sequestration potential for the State of Maryland using remote sensing and ecosystem modeling. Specifically, we will address the following objectives: (1) Improve our existing methodology for carbon stock estimation and uncertainty and assess its efficacy across an expanded range of environmental and forest conditions; (2) Provide local-scale estimates of carbon stocks and their uncertainties for the entire state of Maryland representing Eastern U.S. forest types; (3) Initialize and run a prognostic ecosystem model to estimate carbon stocks and their changes, and to estimate carbon sequestration potential; (4) Provide detailed validation of national biomass maps using FIA data and localscale biomass maps.(5) Demonstrate new data acquisition technology (single photon counting) for lowcost, rapid carbon assessments. Our proposed work will greatly expand our coverage from 2 to 24 Maryland counties and extends from the tidewater forests of the Chesapeake Bay through the coastal plains and uplands, to the mountainous forests of Western Maryland and the Appalachians. This gradient in land use, topographic, edaphic, and climatic conditions enables an appropriate expansion of methods, models, data, and assessments consistent with the goals of the second phase of CMS. Our objectives build from our Phase 1 work and lead to a clear set of tasks for the proposed effort. These are divided into seven categories of activities traceable to this framework: (1) Remote sensing data acquisition and processing; (2) Field data collection and analysis; (3) Algorithm development and image processing; (4) Statistical and machine learning model development; (5) County biomass and uncertainty map generation, and end-to-end error analysis; (6) Prognostic ecosystem modeling, and; (7) national biomass map validations. An additional element of our proposed work is a coordinated outreach effort to county and state agencies to inform and promote their activities in CMS and includes a transfer of technology to the State of Vermont. To promote this outreach we will also implement a new, web-based data visualization, query and delivery system, Grid^Intel Online (GIO) that allows any user to call up lidar data, associated imagery, biomass and error estimates for arbitrary map areas. Deliverables for this project expand upon those from Phase 1. In addition to the developed framework the project will produce the following CMS products: (1)

tiled and mosaicked canopy height and forest/non-forest maps at 2 m and 30 m resolution for Maryland; (2) AGBM maps at 30 m resolution with associated uncertainty maps; (3) EDmodel based carbon and carbon-flux maps at 90 m resolution; (4) ED-model maps of carbon sequestration potential; (5) web-based data visualization and query system; (6) map of canopy structure and biomass derived from wall-to-wall single photon lidar for Alleghany county; (7) assessment of main sources of error and proposed strategies for reducing errors in future deployment of an operational CMS.

Keywords:

Project Associations:

- NASA CMS

Spatial Extents of Study:

- US

CMS:

- Land Biomass
- Decision Support

Participants:

Richard Birdsey, USDA Forest Service
Ralph Dubayah, University of Maryland
George Hurtt, University of Maryland
Anuradha (Anu) Swatantran, UMD
Maosheng Zhao, University of Maryland

Project URL(s): None provided.

Research Contributions:

Contribution	Available by:
Product Title: 1) High resolution forest/non forest, canopy height (1m) and above ground biomass (30m) over Maryland. 2) ED model based biomass and carbon sequestration potential (90m).3) SPL canopy height and biomass maps for Garrett County.	

Description:

- **Objective:** Continued development of a framework for estimating local-scale, high-resolution carbon stocks and future carbon sequestration potential using remote sensing and ecosystem modeling.
- **Inputs/Data products used:** Discrete return lidar, Single photon lidar, landsat disturbance
- **Algorithm/Name of models used:** Linear regression models, Random Forests/BMA, Ecosystem Demography Model
- **Spatial Domain:** Local
- **Time Period:** variable based on lidar acquisition dates(2004-2012)
- **Evaluation:** Biomass from field measurements and allometry. comparisons between empirical and modeled biomass
- **Intercomparison efforts/gaps:** Comparisons between lidar and FIA biomass maps and ED modeled biomass at local scale. Use of local scale maps to validate national scale maps (e.g. Kellndorfer, CMS Phase 1 National Map, Blackard (FIA map))
- **Uncertainty estimates:** 1) pixel-level uncertainty estimates for local scale biomass map. 2) Bayesian based model flexibilty and uncertainty analysis 3) Improved metholdogy for estimating

FIA biomass estimates in 'non-forest' lands and plot-pixel level comparisons with lidar biomass maps

- **Uncertainty categories:** model-data comparison, model-model comparison

Expected Users:

Metadata URL(s):

Data Server URL(s):

Publications: None provided.

4th NACP All-Investigators Meeting Posters:

- A High-Resolution Carbon Monitoring System by Combining Ecosystem Demography Model with Remotely Sensed Land Cover and Canopy Height -- (*Maosheng Zhao*, George Hurtt, Ralph Dubayah, Justin Fisk, Amanda Armstrong, Anuradha Swatantran, Naiara Pinto, Oliver Rourke, Steve Flanagan) [abstract]

French-04 (2012)

Project Title: Development of Regional Fire Emissions Products for NASA's Carbon Monitoring System using the Wildland Fire Emissions Information System

Science Team Members:
Michael Billmire, Michgan Tech Research Institute
Nancy French, Michigan Tech Research Institute (MTRI) (**Project Lead**)
Eric Kasischke, University of Maryland
Donald (Don) McKenzie, USDA Forest Service

Abstract: Current work under the NASA-CMS Flux Pilot project includes measures of biomass burning emissions for the quantification of carbon flux from land to the atmosphere. Fire is recognized as an important mechanism for this exchange. Measures of biomass burning emissions are included in this pilot project, but the estimates would greatly benefit from further refinement, and some idea of the uncertainty in biomass burning emissions is needed. There is a growing community of international, federal, and state-level parties that desire and in some cases require refinements in methods to quantify emissions from wildland and prescribed fire (biomass burning). To meet these requirements, these parties are developing a suite of methods to address their needs. We propose to use tools developed from collaborations with the US Forest Service and US Environmental Protection Agency, as well as recent research carried out for NASA, to refine the fire emissions module of the CASA-GFED model currently used by CMS. For the proposed project, to be conducted in Phase II of the CMS, we are proposing to assist the NASA-Goddard CASA-GFED team in improving the GFED approach currently used in the CMS Phase I Flux Pilot project. We will use the Wildland Fire Emissions Information System (WFEIS), an approach developed under NASA s Carbon Cycle Science program in collaboration with others in the fire emissions community, to adjust GFED estimates over North America. WFEIS operates at a 1-km spatial grid scale, while GFED operates at a 0.5 deg grid scale. The two approaches use the same general construct, however they use different data sources for the model parameters and make different assumptions when applying the general model. WFEIS uses a ground-based method to map biomass (fuel loading) and a more direct method to estimate combustion completeness (fuel consumption) than GFED. WFEIS was developed as a regional to landscape-scale method, making it an appropriate tool to refine the GFED estimates of emissions for areas where the two methods can be implemented. The proposed activity includes: 1) improvements in quantifying mapped fuels (biomass) for the US and combustion in deep organic soils of Alaska; 2) development of an uncertainty measurement methodology for emissions estimation; 3) production of 1-kmscale fire emissions estimates for the US; 4) a comparison of these products to CASAGFED emissions estimates; and 5) refinements of GFED parameters based on the results found with WFEIS. Specific outputs from this activity will provide important information for improving our understanding of carbon emissions from wildland fire.

Keywords:

Measurement Approaches:
- Remote Sensing

Science Questions:
- Attribution

- Modeling
- Decision Support

GHG Compounds:

- Carbon Dioxide
- Carbon Monoxide
- Methane

Project Associations:

- NASA CMS

Spatial Extents of Study:

- Region
- US

CMS:

- Land Biomass
- Land-Atmosphere Flux
- Decision Support

Other Keywords: fire fuels, biomass

Participants:

Michael Billmire, Michgan Tech Research Institute
Nancy French, Michigan Tech Research Institute (MTRI)
Naomi Hamermesh, MTU
Eric Kasischke, University of Maryland
Donald (Don) McKenzie, USDA Forest Service

Project URL(s): None provided.

Research Contributions:

Contribution	**Available by:**
Product Title: spatial map of emissions from wildland and agricultural burning	
Description: • **Objective:** Provide estimates of fire emissions with assessment of uncertianty. Documatation of the model and some imporvements to include mre dynamic input data • **Inputs/Data products used:** • **Algorithm/Name of models used:** Wildland Fire Emissions Information System (WFEIS) • **Spatial Domain:** CONUS • **Time Period:** 1983-2011 • **Evaluation:** • **Intercomparison efforts/gaps:** Site (landscape-scale) comparisons with other fire emissions methods including GFED (French et al 2011) • **Uncertainty estimates:** Developing a full uncertianty estiamtion plan under this grant with some aspects completed. Some part of the model will be difficult to asses, so staregies to complete a full error anaysis will be developed for implementation in future versions of the model. • **Uncertainty categories:** model-data and model-model comparisons	
Expected Users:	
Metadata URL(s):	

	Data Server URL(s):
Publications:	None provided.
4th NACP All-Investigators Meeting Posters:	• Large emissions of carbon dioxide, carbon monoxide, and methane from Alaska boreal fires during the 2000s -- (*Eric S. Kasischke*, Elizabeth E Hoy, Merritt R. Turetsky, Evan Kane, William J deGroot, Nancy HF French) [abstract]

Healey-01 (2012)

Project Title: A Global Forest Biomass Inventory Based upon GLAS Lidar Data

Science Team Members: Sean Healey, USDA Forest Service (**Project Lead**)

Abstract:

The United Nations Food and Agriculture Organization (FAO) compiles and monitors national-level biomass estimates across the world s forests through the Global Forest Resources Assessment (FRA). FRA reports represent the current state of knowledge regarding key forest parameters as expressed by national forest agencies and ministries worldwide. Data collected in the FRA is important to UN initiatives such as REDD (Reducing Emissions from Deforestation and Degradation), which depend upon accurate, precise, and consistent national-level reporting of forest carbon storage. The proposed work would establish a satellite-based NASA CMS global inventory of aboveground tree biomass (a primary component of overall biomass) as an official component of FAO s FRA 2015. Methods for this inventory were developed during the CMS pilot phase though a partnership between members of the CMS national biomass pilot team and representatives of the national forest inventory (FIA: US Forest Service s Forest Inventory and Analysis unit) on the CMS Science Definition Team. Discrete full waveform lidar footprints from the GLAS (Geoscience Laser Altimeter System aboard ICESat) are strongly correlated with aboveground tree biomass, and are here used in a survey/sample context as the basis for the CMS/FAO global biomass inventory. Based upon CMS pilot results, this approach is likely to provide an improvement in the precision of biomass estimates for countries without established national forest inventories, and its global consistency should enhance inter-comparability of biomass stocks across all nations. This inventory would be based upon model-based estimation, an approach which provides clear estimates of biomass and related uncertainty, accounting for both the variance of the sample and variance introduced by modeling biomass at each GLAS shot. FAO will coordinate global compilation of the ground data needed from national forestry agencies for calibration of models to be used in this inventory. A series of approximately 10 regional workshops will be held for national forest inventory representatives from around the world in 2013. At each workshop, time will be dedicated to engage participating countries in the needed data sharing. Almost all costs associated with this effort (including travel and lodging for many participants) will be borne by FAO. In addition to providing country- and global-level forest biomass estimates, this project will publish relationships between GLAS heights and field-measured biomass, which may be of use to other CMS efforts using GLAS data to calibrate wall-to-wall maps. Lastly, there is a forward-looking element which involves forecasting the precision of this inventory approach using lidar data from the ICESat-2 satellite (launch: 2016). Collection of ground data by this project will be coordinated with the ICESat-2 Science Team, which is programming overflights of GLAS shots by MABEL (an ICESat-2 simulation platform) and airborne lidar. Taken together, the components of the proposed project will: 1) develop a global CMS aboveground forest biomass product; 2) establish it as a critical monitoring asset within the FAO FRA monitoring process; and 3) assess its sustainability in view of upcoming NASA missions. The proposed work includes a good deal of in-kind salary contribution from the Forest Service, and there is a 55/45 balance of funding to non-federal/federal entities. Sean Healey, FIA s remote sensing representative to FAO and a member of the CMS Science Definition Team, is nominated for membership on the CMS Science Team.

Keywords:

Project Associations:

- NASA CMS

Spatial Extents of Study:

- US

CMS:

- Land Biomass
- MRV

Participants: Sean Healey, USDA Forest Service

Project URL(s): None provided.

Research Contributions:

Contribution	**Available by:**
Product Title: Table of country-level mean forest biomass values	
Description: • **Objective:** Develop global country-level estimates for mean aboveground forest biomass per hectare in support of the 2015 UN Food and Agriculture Association Forest Resources Assessment. • **Inputs/Data products used:** GLAS LiDAR data and inventory information volunteered by contributing countries • **Algorithm/Name of models used:** Model-based estimation • **Spatial Domain:** global • **Time Period:** 1 estimate, centered around 2005 • **Evaluation:** Estimates can be compared with field-based estimates in countries with an established national forest inventory • **Intercomparison efforts/gaps:** Authors of the UN Forest Resources Assessment, together with country correspondents, will determine whether to include our estimate, an estimate from a dedicated national forest inventory, or an international default. • **Uncertainty estimates:** We have a straightforward variance estimator, based on sample theory, that will provide credible confidence intervals for our country- and global-level estimates. • **Uncertainty categories:** deterministic	
Expected Users:	
Metadata URL(s):	
Data Server URL(s):	

Contribution	**Available by:** Dec 2013
Product Title: Forest Biomass Inventory Based upon GLAS Lidar Data for California	
Description: A pilot study in the US state of California uses model-based estimation methods to estimate biomass using a combination of limited available field data and LiDAR data from the GLAS (Geoscience Laser Altimeter System) sensor aboard ICESat. This approach uses 2 distinct samples: one for building biomass models, consisting of whatever co-located field and GLAS measurements are available; and one consisting of carefully identified representative GLAS measurements where those models are applied to	

provide the “observations” needed to make population estimates. Variance estimators account for uncertainty introduced by using modeled observations.
Expected Users: scientists and others interested in regional to national level biomass and carbon pool estimation
Metadata URL(s):
Data Server URL(s):

Publications: Healey, S.P. P. L. Patterson, S. Saatchi, M. A. Lefsky, A. J. Lister and E. A. Freeman. 2012. A sample design for globally consistent biomass estimation using lidar data from the Geoscience Laser Altimeter System (GLAS). Carbon Balance and Management, 7:10

Houghton-02 (2012)

Project Title: Spatially Explicit Sources and Sinks of Carbon from Deforestation, Reforestation, Growth and Degradation in the Tropics: Development of a Method and a 10 Year Data Set 2000-2010

Science Team Members: Richard (Skee) Houghton, The Woods Hole Research Center (**Project Lead**)

Abstract: Neither of the pilot studies in NASA s Phase 1 of the CMS has explicitly considered changes in terrestrial carbon storage that result from land use and land-cover change (LULCC). The biomass pilot study could be extended to estimate changes in aboveground carbon density, but modeling and ancillary data will be needed to account for changes in soils, downed wood, and wood products. The flux pilot study has, so far, concentrated on short-term fluxes of carbon (i.e., photosynthesis, respiration, etc.) and has paid less attention to the longer-term, structural changes that result from disturbance and recovery. Yet it is these changes in biomass and soil carbon that define the net contribution of LULCC to the global carbon budget. We propose (1) to develop and demonstrate a method for monitoring changes in carbon density in forests and (2) to produce a map of gross and net fluxes of carbon associated with deforestation, reforestation, growth and degradation for the entire tropics. We will focus on the changes in carbon density that result from disturbance and recovery. We propose to use multi-scale changes in forest cover (gains and losses) combined with lidar-based estimates of aboveground carbon density to inform a carbon-tracking model that will calculate losses and gains of carbon at a spatial resolution of 250m across the tropics and at a resolution of 30m for two regions within southeast Asia and the Congo Basin. As a part of this research, we will determine the propagation of error for each method (change in land cover, change in carbon density), including allometry error and modeling error. The analysis of error will help define how small a disturbance (in area and in carbon density) can be observed. And, using a carbon tracking model, we will investigate the effect of this minimum detection on carbon emissions. The work proposed here will complement the current pilot studies and will track changes in terrestrial carbon density, in particular the changes that result from disturbance and recovery of forests. The model will use a combination of MODIS, Landsat, and GLAS data to determine annual changes in carbon density in aboveground living and dead biomass, belowground biomass, litter, coarse woody debris, and wood products. The work will focus on identifying, characterizing, and measuring disturbances (and recovery) and on calculating the resulting fluxes of carbon. The products of this work will be (1) a methodological approach incorporating satellite data, a carbon-tracking model, and error analyses, and (2) multi-scale gridded data sets showing the distribution of carbon sources and sinks attributable to forest disturbance and recovery. The method will not be limited to the data inputs used here. Rather the model will be flexible enough to accommodate other data sets as they evolve. The products will include the data sets used to calculate carbon sources and sinks (rates and intensities of disturbance and aboveground carbon densities), the errors in each data set and the propagation of error through the calculation of net carbon flux. The work is relevant to societal needs in two ways: first, carbon emissions from LULCC are an important but poorly constrained component in the global carbon balance; this work will demonstrate the capacity of satellite-based measurements to reduce the error of that flux. Second, project-level and national-level emissions are the basis for evaluating emission reduction strategies, arguably the most effective mechanism for reducing emissions of carbon from developing countries.

Keywords:

Project Associations:

- NASA CMS

Spatial Extents of Study:

- US

CMS:

- Land Biomass
- MRV

Participants: Richard (Skee) Houghton, The Woods Hole Research Center

Project URL(s): None provided.

Research Contributions:

Contribution	Available by:
Product Title: Tropics-wide annual changes in forest area from Landsat. tropics-wide aboveground carbon density from GLAS data.	
Description: • **Objective:** Develop a method using satellite data for estimating gross and net sources and sinks of carbon from deforestation, reforestation, growth, and degradation of forests. • **Inputs/Data products used:** Landsat data; GLAS data; MODIS data • **Algorithm/Name of models used:** • **Spatial Domain:** Tropical forests • **Time Period:** 2000-2010 • **Evaluation:** • **Intercomparison efforts/gaps:** • **Uncertainty estimates:** Errors associated with changes in forest area and aboveground carbon density will be analyzed. • **Uncertainty categories:** model-data comparison	
Expected Users:	
Metadata URL(s):	
Data Server URL(s):	

Contribution	Available by:
Product Title: Tropics-wide estimate of net and gross fluxes of carbon from deforestation, reforestation, growth, and degradation.	
Description: • **Objective:** Determine the distribution of sources and sinks of carbon from deforestation, reforestation, growth and degradation in the tropics for the period 2000-2010.	

- **Inputs/Data products used:**
- **Algorithm/Name of models used:** Spatial bookkeeping model
- **Spatial Domain:** Tropical forests
- **Time Period:** 2000-2010
- **Evaluation:** Previous estimates of tropical emissions from land use and land-cover change
- **Intercomparison efforts/gaps:**
- **Uncertainty estimates:** Errors associated with modeled net and gross fluxes of carbon will be analyzed.
- **Uncertainty categories:** model-data comparison

Expected Users:

Metadata URL(s):

Data Server URL(s):

Publications: None provided.

Huntzinger-01 (2012)

Project Title: Reduction in Bottom-Up Land Surface CO2 Flux Uncertainty in NASA's Carbon Monitoring System Flux Project through Systematic Multi-Model Evaluation and Infrastructure Development

Science Team Members:
Joshua Fisher, JPL
Deborah Huntzinger, Northern Arizona University (**Project Lead**)
Christopher Schwalm, Northern Arizona University

Abstract: This study will generate improved global estimates of land-atmosphere carbon exchange by combining and enhancing the technical infrastructure and observational constraints within the NASA Carbon Monitoring System (CMS) Flux Project with new “bottom-up” a priori surface flux estimates. These new surface flux products will be derived from a community of models that represent our best process-based understanding of how carbon is exchanged between the land and the atmosphere. We will leverage and build off of an existing NASA funded grant: The Multi-Scale Synthesis and Terrestrial Model Intercomparison Project (MsTMIP). MsTMIP is a coordinated, large-scale intercomparison effort that combines common forcing data and a detailed simulation protocol in order to improve the diagnosis and attribution of carbon sources and sinks across both global and regional scales. What MsTMIP does that other intercomparisons have failed to do, is create a framework that isolates, interprets, and helps inform understanding of how differences in process parameterizations among current “bottom-up” models impact their flux estimations. As a result, the MsTMIP framework allows for the isolation and quantification of the intermodel variance in estimates of land-atmosphere carbon exchange due to model structure, or variations in the types of processes consider in the model and how these process are represented. This inter-model variance provides a robust assessment of uncertainty in land surface priors due to varying model physics, a component currently missing from the CMS-Flux system. CMS-Flux has the ability to produce ensembles of atmospheric CO2 distributions using perturbations to transport and surface fluxes. These ensembles can help build understanding of the relationship between surface flux and atmospheric CO2 concentrations, particularly if the consistency (or inconsistency) between surface flux representations and atmospheric CO2 measurements can be linked back to representation of processes within the models. However, to do so

effectively CMS-Flux needs to include a priori flux estimates that are more representative of our current understanding of landatmosphere sources and sinks than what is currently in the system. In other words, the a priori flux estimates need to be informed by the range of models used by the scientific community given that there is no consensus on the “best” model overall. CMS-Flux is currently limited with respect to the land surface bottom-up priors because: 1) it uses only two closely related land surface models, and as a result has a restricted representation of the “true” uncertainty in the land surface bottom-up fluxes; 2) the uncertainty in the bottom-up fluxes themselves is not quantified in the system; and, 3) the atmospheric inversion system is disconnected from the TBMs in that one unified system cannot currently be run. This proposed effort improves the current CMS-Flux product with four key advances. First, we propose to leverage the existing NASA funded MsTMIP activity to generate new a priori “bottom-up” land-surface flux products for the CMS-Flux system. Second, we will quantify uncertainties in a priori flux estimates. Third, we will develop the technical infrastructure of CMS-Flux to handle multiple land-surface models as priors. Four, we will combine the new a priori input products with the enhanced CMS infrastructure to test the influence of prior flux estimates (and their associated uncertainty) on posterior flux estimations from the inversion.
Finally, the new infrastructure will also be used to compare existing terrestrial biospheric model estimates to the atmospheric CO2 constraints within CMS-Flux, providing another means of evaluating understanding of the processes controlling land-atmosphere carbon exchange. Combined, this proposed activity will expand the operational-use of CMS-Flux and allow for more robust posterior flux estimates and their associated uncertainties.

Keywords:

Project Associations:

- NASA CMS

Spatial Extents of Study:

- US

CMS:

- Land-Atmosphere Flux

Participants:

Dominique Bachelet, Oregon State University
Joshua Fisher, JPL
Deborah Huntzinger, Northern Arizona University
Christopher Schwalm, Northern Arizona University

Project URL(s): None provided.

Research Contributions:

Contribution	**Available by:**
Product Title: Global terrestrial net CO2 fluxes	

Description:

- **Objective:** Objective (1): Provide improved land-surface input products to the CMS-Flux system using the multi- model ensemble from MsTMIP:
  Objective (2): Develop the technical infrastructure of CMS to handle an integrated multi-LSM system for operational use.
  Objective (3): Evaluate the consistency of MsTMIP model estimates with atmospheric CO2 observations, providing an additional benchmark of land-surface model performance.
- **Inputs/Data products used:** Primarily meteorology, some remote sensing for LAI
- **Algorithm/Name of models used:** Multiple terrestrial biosphere models through MsTMIP
- **Spatial Domain:** Global
- **Time Period:** 1901-2010

- **Evaluation:** Multiple benchmark datasets
- **Intercomparison efforts/gaps:** This project is based on an intercomparison
- **Uncertainty estimates:** The primary objective is to provide structural uncertainty from the multi-model ensemble for the GEOS-Chem atmospheric inversion model.
- **Uncertainty categories:** model-model comparison

Expected Users:

Metadata URL(s):

Data Server URL(s):

Publications: None provided.

Jacob-01 (2012)

Project Title: Use of GOSAT, TES, and Suborbital Observations to Constrain North American Methane Emissions in the Carbon Monitoring System

Science Team Members: Daniel Jacob, Harvard University (**Project Lead**)
Steven (Steve) Wofsy, Harvard University

Abstract: We propose to contribute to the NASA Carbon Monitoring System (CMS) with a fourdimensional variational (4D-var) inverse modeling capability for methane emissions in North America integrating satellite (GOSAT, TES), aircraft (CalNex, HIPPO, NOAA/CCGG), and surface-based (TCCON, NOAA/CCGG) observations. Our work will build on the existing CMS capability at JPL for carbon flux inversions using the adjoint of the global GEOS-Chem chemical transport model (CTM). Here we will apply the adjoint of the nested version of GEOS-Chem with 1/2o × 2/3o (~50 × 50 km2) horizontal resolution over North America and adjacent oceans. The nested model will enable fine-scale constraints on methane sources through the 4D-var inversion. We will focus on 2009 2011 when data from both GOSAT and TES are available together with aircraft campaign data over the US from CalNex (May July 2010) and HIPPO (June September 2011). Combined use of GOSAT and TES data will enable us to separate boundary layer and free tropospheric contributions to the methane column through the inversion. The satellite data will be ingested in the 4D-var inverse model while the suborbital data will be used for independent analysis of the optimized methane fluxes. We will conduct a targeted analysis of the CalNex period to constrain methane sources in California by applying both Lagrangian (STILT) and Eulerian (GEOS-Chem) inverse modeling approaches to the aircraft and satellite data, testing the effect of different meteorological data sets and of different a priori constraints. This analysis will provide a unique opportunity to assess inverse modeling uncertainties related to resolution, data type (satellite or aircraft), meteorological model, and inversion procedure. We will use results from our continental-scale inversion of methane fluxes to better understand and quantify the major sources contributing to methane emissions in North America, and to provide guidance to the US EPA for improving its national emission inventories. The inverse modeling capability for methane will be implemented into the existing CMS Flux Pilot Project at JPL for consistent inversion of CO2 and methane fluxes over North America using the same 4D-var system. This will provide a powerful facility to monitor the fluxes of the two most important anthropogenic greenhouse gases. Our work will be directly responsive to major climate policy initiatives in the US targeting methane emissions including the Global Climate Change and Clean Air Initiative of the US State Department and the Global Methane Initiative of the U.S. EPA. P.I. Daniel Jacob and CoI Steve Wofsy will join the CMS Science Team as part of this project.

Keywords:

GHG Compounds:
- Methane

Project Associations:
- NASA CMS

Kasischke-03 (2012)

Project Title: The Forest Disturbance Carbon Tracking System A CMS Phase 2 Study

Science Team Members: Eric Kasischke, University of Maryland (**Project Lead**)

Abstract: Forest disturbances are a key process that drives significant variations in the terrestrial carbon budget for North America. While many NASA funded projects for the North American Carbon Program, as well as others funded by U.S. land management agencies, were focused on developing approaches to map forest disturbances, and assess the impacts of these disturbances on carbon cycling. However, efforts have not progressed enough to integrate the results from these efforts in order to provide a forest disturbance product that is useful for assessing the impacts of disturbances. The goal for this proposed Carbon Monitoring System (CMS) pilot project is to (1) develop a new regional carbon monitoring product that utilizes satellite remote sensing data to map forest disturbed area on an annual basis at medium resolution; and (2) to use this product as a basis for assessing the impacts of disturbance on forest carbon stocks for specific ecoregions of the United States. The development of the Forest Disturbance Carbon Tracking System (FDCTS) will provide an approach based on using a number of information products derived from remotely sensed data to address the following objectives: (a) Integrate a number of forest disturbance products in systematic fashion to create a map of the spatial and temporal extent of different forest disturbance events and episodes; and (b) Assess the impacts of these disturbances on key forest characteristics that control changes to carbon cycling (tree mortality, damage to branches and foliage, loss of live biomass, harvest removals, and combustion) for specific forest types in two North American forest ecoregions in order to produce a data product that depicts changes to forest carbon stocks on an annual basis for the ecoregions being studied. This CMS pilot project would focus on forest disturbances in two Level II U.S. ecoregions where disturbances have been dominant drivers of the terrestrial carbon cycle over the past decade: (a) the Western Cordillera ecoregion which has experienced major outbreaks of pine bark beetles as well as wildfire; and (b) the Alaska Boreal Interior ecoregion where burning of deep organic layers during fires represents the major impact on forest carbon cycles. As part of this pilot project, for each ecoregion, we would develop disturbance maps and forest impact products for the 2000s on an annual basis. The outputs from thithis CMS pilot project would be medium resolution (30 m) maps of all forest disturbances in the study ecoregions, which also contains data layers on pre-disturbance forest and carbon pool characteristics, the impacts of forest disturbances on carbon pools, and the amount of carbon remaining after the disturbances for specific pools. Within the climate change area, reliable and up-to-date information is needed on the terrestrial sources and sinks for a number of carbon-based greenhouse gases. The results from this pilot project will demonstrate a new approach for integrating multiple data sources to generate a product that quantifies the impacts of forest disturbance on the primary forest carbon pools. This new data product would not only provide the basis for providing inputs into models that quantify the impacts of disturbances on carbon cycling, but also to validate such models. The pilot project not only represents the first step towards creating national and continental-scale forest disturbance products, but also would provide the foundation for developing a system that would be able to quantify the impacts of forest disturbances on an annual basis going back thirty years to the mid-1980s (based on exploiting the Landsat TM/ETM+ data archive). Such an analysis would not only provide scientists, managers, and policy makers with clearer information on the integrated impacts of past disturbances, but the approach could be used to provide improved information on the impacts of forest disturbance on an annual basis.

Keywords:

Measurement Approaches:

- Remote Sensing
- Modeling

Science Questions:

- Diagnosis

GHG Compounds:

- Carbon Dioxide
- Carbon Monoxide
- Methane

Project Associations:

- NASA CMS

Kennedy-01 (2012)

Project Title: Integrating and Expanding a Regional Carbon Monitoring System into the NASA CMS

Science Team Members:
Van Kane, University of Washington
Robert Kennedy, Boston University (**Project Lead**)
Neeti Neeti, Boston University
Scott Powell, Montana State University

Abstract: A key challenge in a carbon monitoring system is scaling thematically rich but highly localized information to the broad spatial scales needed for carbon accounting and management. This is particularly true for wooded ecosystems, where carbon storage potential is high, but actual carbon status is highly determined by local-scale environmental and forest management conditions. Through a USDA-NIFA funded project entitled Integrated, observation-based carbon monitoring for wooded lands of Washington, Oregon and California , our team is developing a system to integrate Landsat satellite imagery, maps of environmental characteristics, Forest Inventory and Analysis (FIA) plot data, small-footprint lidar data, and aerial photos to characterize key carbon dynamics in forested ecosystems across all ownerships in the states of Washington, Oregon, and California from 1985 to 2010. Key characteristics of our system include: ' Operational scaling of local-scale dynamics to all forests in Washington, Oregon, and California ' Yearly mapping of forest biomass and change in biomass from 1990 to 2010 ' Explicit characterization of cause of change ' Integration of USDA Forest Service Forest Inventory and Analysis (FIA) plot data ' Linkage of small-footprint lidar data with regional scale biomass maps ' Explicit quantification of methodological uncertainties for all estimates Because our approach addresses key challenges faced by the current NASA Carbon Monitoring System (CMS), we believe it has the potential to complement and aid NASA s mandate for operational carbon monitoring. To help reach that potential, we propose three activities. -- 1. We will utilize the products from our own carbon monitoring program in forests of Washington, Oregon, and California to evaluate, understand, and improve performance of the NASA CMS products, and compare a variety of national-scale products both to each other and to FIA plot estimates. -- 2. We will work with collaborators within the USDA FIA to extend our approaches to a different forest system, linking explicitly with the local-scale NASA CMS efforts in eastern forests. -- 3. Finally, we will bring our data, methods, and lessons-learned to NASA CMS Science Definition Team, and work closely with other SDT members to link our approaches into those analytical and modeling frameworks to further the overarching goals of the CMS. The following characteristics of our project are relevant to NASA s need to evaluate and improve its CMS: - Evaluating the utility and characterizing uncertainties in CMS products - Understanding scaling issues needed to link local to national scale products - Developing and demonstrating feasibility of alternative approaches to monitoring - Illustrating capabilities of satellite-based monitoring for science and management

Keywords:

Project Associations:
- NASA CMS

Spatial Extents of Study:
- US

CMS:
- Land Biomass
- Decision Support

Participants:
Van Kane, University of Washington
Robert Kennedy, Boston University
Neeti Neeti, Boston University
Scott Powell, Montana State University

Project URL(s): None provided.

Research Contributions:

Contribution	Available by:
Product Title: Forest biomass annually from 1990 to 2010 at 30m grain size; maps of forest disturbance by agent, severity, and timing	

Description:

- **Objective:** 1. Aid CMS evaluation of biomass products using our own Landsat/lidar/FIA plot-based forest carbon monitoring system. 2. Test our system (developed in western forests) in eastern forests
- **Inputs/Data products used:** Landsat time series; Forest Inventory and Analysis plot data (all occasions); small-footprint lidar data and associated field data
- **Algorithm/Name of models used:** Landsat analysis: LandTrendr time series algorithms; lidar: various regression-based approaches; Imputation: canonical correspondance analysis, k-neighbor imputation
- **Spatial Domain:** Obj 1: WA, OR, CA forest lands; Obj 2: Harvard Forest and environments (MA), Savanna River forest and environs (SC/GA)
- **Time Period:** 1990-2010
- **Evaluation:** Cross-validation of imputation models with observations using leave-one-out approaches; Comparison of Landsat-scale with lidar-scale biomass estimates at selected locations
- **Intercomparison efforts/gaps:** Comparison to national scale maps (NBCD, FIA, CMS P1) Comparison at select sites to lidar-based estimates
- **Uncertainty estimates:** To characterize uncertainty in our core imputation steps, we will use the cross-validation results. That measure of uncertainty is aspatial, however. For spatially-explicit estimates of uncertainty, we will produce multiple runs of the entire prediction system for all pixels, and use the variability as an estimate of uncertainty. The multiple runs will vary in three categories: 1. different strategies for time-series analysis of Landsat imagery; 2. different approaches to drawing plot data in imputation space; 3. different allometric equations to convert plot-level tree data to plot-wide biomass estimates.
- **Uncertainty categories:** model-model comparison

Expected Users:

Metadata URL(s):

Data Server URL(s):

Publications: None provided.

Lohrenz-04 (2012)

Project Title: Development of Observational Products and Coupled Models of Land-Ocean-Atmospheric Fluxes in the Mississippi River Watershed and Gulf of Mexico in Support of Carbon Monitoring

Science Team Members: Steven (Steve) Lohrenz, University of Massachusetts Dartmouth (**Project Lead**)

Abstract: Information about carbon fluxes in continental margins and linkages to terrestrial carbon cycles is key focus of NASA s Earth Science Research Program and a central aspect of NASA s Carbon Monitoring System. The uncertainties in coastal carbon fluxes are such that the net uptake of carbon in the coastal margins

remains a poorly constrained term in global budgets. In particular, our ability to estimate current air-sea CO2 fluxes in continental margins is limited, and there is even less capability for predicting changes in the CO2 uptake capacity in coastal waters. The need to improve the understanding of coastal carbon dynamics and precision of estimates of coastal carbon fluxes has implications for attribution of land sources and sinks because atmospheric inversions are sensitive to uncertainties in coastal boundaries. Moreover, characterization of trends in carbon inventories reveal an increasing fraction of fossil fuel carbon is remaining in the atmosphere due to reductions in the efficiencies of ocean sinks and other sink processes not considered in current models. The proposed research will employ a combination of models and remotely-sensed and in situ observations to develop georeferenced products and associated uncertainties for land-ocean exchange of carbon, air-sea exchanges of carbon dioxide, and coastal to open ocean exchanges of carbon. Such information is critically needed to better constrain the contribution of coastal margins to carbon sources and sinks and improve capabilities to attribute sources and sinks to different regions as well as reducing uncertainties in estimates. The proposed effort will use a combination of observations and coupled terrestrial and ocean models to examine carbon processes and fluxes from the watershed to the continental margin. A major aspect of this proposed project will be to establish and populate geospatial portals for sharing and analysis of carbon datasets and products. The primary region of study will be the Mississippi River watershed and northern Gulf of Mexico. However, the model domain will also include the continental margins of Florida and the South Atlantic Bight. The region of study provides an excellent setting to carry out this work as there are a large number of supporting datasets and on-going programs that will complement this work. The proposed work is closely aligned with objectives of the NASA Carbon Monitoring System scoping effort and of the North American Carbon Program and will support National Climate Assessment activities. The effort will also contribute to NASA Coastal Carbon Synthesis effort and international efforts to develop a North American carbon budget (CarboNA). The unique nature of our approach, coupling models of terrestrial and ocean ecosystem dynamics and associated carbon processes, will allow for assessment of how societal and human-related LCLUC, as well as climate change, affects terrestrial carbon sources and sinks, export of materials to coastal margins, and associated carbon processes in the continental margins. Results would also benefit efforts to describe and predict how land cover and land use changes impact coastal water quality, including possible effects of coastal eutrophication, hypoxia, and ocean acidification.

Keywords:

Measurement Approaches:

- Remote Sensing
- In Situ Measurements
- Modeling

Science Questions:

- Diagnosis
- Prediction
- Decision Support

GHG Compounds:

- Carbon Dioxide

Project Associations:

- NASA CMS

Coastal Synthesis:

- Gulf of Mexico

Spatial Extents of Study:

- US

CMS:

- Land-Atmosphere Flux
- Ocean-Atmosphere Flux
- Land-Ocean Flux
- Decision Support

Participants:

Wei-jun Cai, University of Georgia
Ruoying He, North Carolina State University
Stephan Howden, University of Southern Mississippi
Steven (Steve) Lohrenz, University of Massachusetts Dartmouth
Hanqin Tian, Auburn University

Project URL(s): None provided.

Research Contributions:

Contribution	**Available by:**
Product Title: land-ocean fluxes of dissolved and particulate inorganic and organic carbon and nitrogen, air-sea fluxe of carbon dioxide, shelf-ocean exchange of carbon and nitrogen	
Description: • **Objective:** Terrestrial-ocean interface domain. Proposed research will employ a combination of models and remotely-sensed and in situ observations to develop georeferenced products and associated uncertainties for land-ocean exchange of carbon, air-sea exchanges of carbon dioxide, and coastal to open ocean exchanges of carbon. • **Inputs/Data products used:** various • **Algorithm/Name of models used:** DLEM, SABGOM ROMS, other • **Spatial Domain:** Mississippi River watershed, Gulf of Mexico, South Atlantic Bight • **Time Period:** 1904-1910, 2004-2010 • **Evaluation:** USGS monitoring data, ship-based observations, NOAA Ocean Acidification monitoring program • **Intercomparison efforts/gaps:** • **Uncertainty estimates:** We will focus on quantifying the estimation errors and uncertainties induced by modeling algorithms, model parameters, input data and the coupling between land and ocean models. Formal assessment of uncertainty in coupled land surface-ocean models includes several steps: (1) identification of the output(s) of interests, (2) identification of a limited set of input parameters to which outputs are most sensitive, and that may vary depending on the output of interest, (3) development of the distributions for inputs and their correlation structure, (4) design and evaluation of a Monte Carlo experiment. The input parameters exhibiting the highest model sensitivity will be identified and studied in more detail. • **Uncertainty categories:** ensemble	
Expected Users:	
Metadata URL(s):	
Data Server URL(s):	

Contribution	**Available by:** Oct 2012
Product Title: Sea Surface pCO2 measurements in the Gulf of Mexico during the Ocean Survey Vessel Bold cruises in 2006	
Description: Cai, W.-J., Y. Wang, and W.-J. Huang. 2012. Sea Surface pCO2 measurements in the Gulf of Mexico during the Ocean Survey Vessel Bold cruises in 2006. http://cdiac.ornl.gov/ftp/oceans /UG_GoM_UW_Data/2006.data. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, US Department of Energy, Oak Ridge, Tennessee. doi: 10.3334/CDIAC	

/OTG.UG_GOM_UW_2006
Expected Users: Researchers, carbon management stakeholders, modelers
Metadata URL(s): http://cdiac.ornl.gov/ftp/oceans/UG_GoM_UW_Data/2006.data/GM0606_Meta.html
Data Server URL(s): http://cdiac.ornl.gov/ftp/oceans/UG_GoM_UW_Data/2006.data

Contribution	**Available by:** Oct 2012
Product Title: Sea Surface pCO2 measurements in the Gulf of Mexico during the Ocean Survey Vessel Bold cruises in 2007	
Description: Cai, W.-J., Y. Wang, and W.-J. Huang. 2012. Sea Surface pCO2 measurements in the Gulf of Mexico during the Ocean Survey Vessel Bold cruises in 2007. http://cdiac.ornl.gov/ftp/oceans /UG_GoM_UW_Data/2007.data. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, US Department of Energy, Oak Ridge, Tennessee. doi: 10.3334/CDIAC /OTG.UG_GOM_UW_2007	
Expected Users: Researchers, carbon management stakeholders, modelers	
Metadata URL(s): http://cdiac.ornl.gov/ftp/oceans/UG_GoM_UW_Data/2007.data/GM0705_Meta.html	
Data Server URL(s): http://cdiac.ornl.gov/ftp/oceans/UG_GoM_UW_Data/2007.data	

Publications:

Huang W-J, Cai W-J, Castelao RM, Wang Y, Lohrenz SE (2013) Impacts of a wind-driven cross-shelf large river plume on biological production and CO2 uptake in the Gulf of Mexico during spring. Limnology and Oceanography. doi: 10.4319/lo.2013.58.5.1727

Xue Z, He R, Fennel K, Cai WJ, Lohrenz S, Hopkinson C (2013) Modeling ocean circulation and biogeochemical variability in the Gulf of Mexico. Biogeosciences Discuss 10:7785-7830 doi: 10.5194/bgd-10-7785-2013

Liu M, Tian H, Yang Q, Yang J, Song X, Lohrenz SE, Cai W-J (2013) Long-term trends in evapotranspiration and runoff over the drainage basins of the gulf of Mexico during 1901-2008. Water Resources Research 49:1–25 doi: 10.1002/wrcr.20180

Chen, G., H. Tian, C. Zhang, M. Liu, W. Ren, W. Zhu, A. Chappelka, S. Prior and G. Lockaby. 2012. Drought in the Southern United States over the 20th century: Variability and its impacts on terrestrial ecosystem productivity and carbon storage. Climatic Change doi: 10.1007/s10584-012-0410-z

Guo, X., Cai, W.-J., Huang, W.-J., Wang, Y., Chen, F., Murrell, M.C., Lohrenz, S.E., Jiang, L.-Q., Dai, M., Hartmann, J., Lin, Q., & Culp, R. (2012). Carbon dynamics and community production in the Mississippi River plume. Limnology and Oceanography, 57(1), 1-17. doi: 10.4319/lo.2012.57.1.0001

Hopkinson, C. S., W.-J. Cai, and X. Hu. 2012. Carbon sequestration in wetland dominated coastal systems: a global sink of rapidly diminishing magnitude. Current Opinion in Environmental Sustainability, 4:1-9. doi: 10.1016/j.cosust.2012.03.005

Huang, W.-J., Cai, W.-J., Powell, R. T., Lohrenz, S. E., Wang, Y., Jiang, L.-Q. and Hopkinson, C. S. 2012. The stoichiometry of inorganic carbon and nutrient removal in the Mississippi River plume and adjacent continental shelf. Biogeosciences, 9, 1–12, 2012, doi: 10.5194/bg-9-1-2012

Huang, W.-J., Y. Wang, and W.-J. Cai (2012) Assessment of sample storage techniques for total alkalinity and dissolved inorganic carbon in seawater. Limnology and Oceanography-Methods:10, 711-717, doi: 10.4319/lom.2012.10.711

Tian, H., C. Lu, G. Chen, B. Tao, S. Pan, S. Del Grosso, X. Xu, L. Bruhwiler, S. Wofsy, E. Kort, and S. Prior. 2012. Contemporary and projected biogenic fluxes of methane and nitrous oxide in terrestrial ecosystems of North America. Frontiers in Ecology and the Environment http://dx.doi.org/10.1890/120057

Tian, HQ, G. Chen, C. Zhang, M. Liu, G. Sun, A. Chappelka, W. Ren, X. Xu, C. Lu, S. Pan, H. Chen, D. Hui, S. McNulty, G. Lockaby and E. Vance. 2012. Century-scale response of ecosystem carbon storage to multifactorial global change in the Southern United States. Ecosystems doi: 10.1007/s10021-012-9539-x

Xu, X. F., Tian, H. Q., Chen, G. S., Liu, M. L., Ren, W., Lu, C. Q., and Zhang, C. 2012. Multifactor controls on terrestrial N2O flux over North America from 1979 through 2010, Biogeosciences, 9, 1351-1366. doi: 10.5194/bg-9-1351-2012

Zhang, C., H. Tian, G. Chen, A. Chappelka, X. Xu, W. Ren, D. Hui, M. Liu, C. Lu, S. Pan, G. Lockaby. 2012. Impacts of Urbanization on Carbon Balance in Terrestrial Ecosystems of the Southern United States. Environmental Pollution 164, 89-101. http://dx.doi.org/10.1016/j.envpol.2012.01.020

4th NACP All-Investigators Meeting Posters:

- Impacts of terrestrial exports on carbon dynamics of the northern Gulf of Mexico -- (*Wei-jun Cai*) [abstract]
- Impacts of Population Growth, Urbanization and Agricultural Expansion on Riverine Fluxes and Coastal Ecosystems in the Southeastern U.S. as assessed by the Coupled Land-Ocean Modeling System, Part 1: Riverine Flux Variations -- (*Hanqin Tian*, Ruoying He, Wei Ren, Bo Tao, Jia Yang, Chaoqun Lu, Qichun Yang, Bowen Zhang, Zuo Xue, Joseph Zambon, Wei-jun Cai, Steven Lohrenz) [abstract]
- Impacts of Population Growth, Urbanization and Agricultural Expansion on Riverine Fluxes and Coastal Ecosystems in the Southeastern U.S. as assessed by the Coupled Land-Ocean Modeling System, Part 2: Marine Ecosystem Responses -- (*Ruoying He*, Hanqin Tian, Zuo Xue, Joseph Zambon, Zhigang Yao, Wei Ren, Chaoqun Lu, Bo Tao, Wei-jun Cai, Steven Lohrenz) [abstract]

Miller-J-01 (2012)

Project Title: In Situ CO2-Based Evaluation of the Carbon Monitoring System Flux Product

Science Team Members: John Miller, NOAA Earth System Research Laboratory (**Project Lead**)

Abstract: The fundamental objective of the NASA Carbon Monitoring System (CMS) flux product is to derive surface CO2 fluxes using satellite-based column CO2 mole fractions. Although the CMS flux product has an existing evaluation strategy, it is limited in scope and has acknowledged shortcomings, especially with regard to tropical carbon fluxes. Here, we propose to use the large number of high-accuracy, high-precision, globally distributed in situ tropospheric CO2 observations (including a unique set of tropical observations) to assess the realism of the optimized CMS fluxes and their stated uncertainties. First, CO2 observations will be compared directly with a posteriori CMS-modeled CO2 mole fractions. To first-order, near surface CO2 surpluses in the modeled CO2 mole fractions can be interpreted as excess positive surface flux, and vice versa. Second, CMS fluxes will be compared to fluxes derived from independent flux optimization systems (using in situ CO2 data). This more direct flux evaluation will be conducted globally using the CarbonTracker data assimilation system. Moreover, CarbonTracker will be run using multiple transport models to help assess the role of transport errors in the mismatch between simulation and observation. Additionally, in tropical South America we will use a state of the art regional flux inversion system to create a second set of fluxes, taking advantage of a two-year data set of fortnightly measurements in Brazil at four vertical profile sites and two additional surface sites. Tropical South America is of particular interest in global satellite-based inversions because of its disproportionate importance for the global carbon cycle combined with the anticipated seasonal biases in tropical satellite-based column CO2 arising from frequent cloud cover and high aerosol loadings. Working with the CMS flux product team, we will use the in situ CO2-based flux evaluations to diagnose shortcomings in the existing CMS flux optimization approach, transport parameterization and input GOSAT/ACOS CO2 columns. Finally, while we do expect OCO-2 to ultimately have better coverage than GOSAT over tropical South America, we still anticipate significant seasonal biases in sensitivity to Amazonian surface fluxes. To address this issue, and guard against biases in eventual CO2 flux optimization, we will produce an in situ CO2-optimized flux map for use as a prior in future CMS flux products. For any top-down CO2 flux estimation system, evaluation and uncertainty

characterization is as important as the flux calculation itself, and the research proposed here will leverage the highest precision measurements in the global carbon cycle to assess the quality of the CMS flux product.

Keywords:

Project Associations:

- NASA CMS

Spatial Extents of Study:

- Global
- US

CMS:

- Atmospheric Transport
- Land-Atmosphere Flux

Participants: John Miller, NOAA Earth System Research Laboratory

Project URL(s): None provided.

Research Contributions:

Contribution	**Available by:**
Product Title: comparison between observed CO2 and a posteriori modeled CO2 from the CMS flux product (Bowman et al.)	
Description: • **Objective:** Use independent (in situ) CO2 observations, mainly from the NOAA network, to evaluate the CMS flux product. • **Inputs/Data products used:** NOAA in situ CO2; IPEN (Brazil) in situ CO2 • **Algorithm/Name of models used:** GEOS-Chem output (from Bowman/Liu) • **Spatial Domain:** Global • **Time Period:** 2009-2011 • **Evaluation:** see Objective • **Intercomparison efforts/gaps:** see Objective • **Uncertainty estimates:** distributions and summary stats of differences between observed and modeled CO2 • **Uncertainty categories:** model-data comparison	
Expected Users:	
Metadata URL(s):	
Data Server URL(s):	

Publications: None provided.

Pawson-01 (2012)

Project Title: GEOS-CARB: A Framework for Monitoring Carbon Concentrations and Fluxes

Science Team Members:

David Baker, CIRA Colorado State Univ.
Stephan (Randy) Kawa, NASA GSFC
Tomohiro (Tom) Oda, Colorado State University and NOAA Earth System Research Lab
Steven Pawson, NASA GMAO (**Project Lead**)

Abstract:

This proposal is for a continuation of NASA GSFC s activities related to the Carbon Monitoring System, Flux Pilot Study (CMS FPP). The work will enhance and develop the capabilities of NASA s Goddard Earth Observing System (GEOS) set of models and assimilation components to further develop a core capability for CMS-related carbon cycle science and monitoring. The work consists of three components: (i) continuation of past work to compute atmosphere-ocean and atmosphere-land biosphere fluxes, as well as their evaluation using forward modeling in GEOS-5; (ii) enhancements of GEOS-5 for carbon monitoring, including a model study of the intermingling of uncertainties in anthropogenic and land-biospheric carbon emissions, and development of an enhanced assimilation capability to include multiple space-borne CO2 estimates (from AIRS and ACOS-GOSAT); (iii) a focused activity that examines aspects related to top-down (inverse) estimates of carbon fluxes. The latter effort will include a controlled comparison of three inverse estimates, including the one from CMS FPP, that use the same input data but use different methods. It also includes the implementation and application of a Lagrangian particle dispersion model to compute global footprints of GOSAT observations. Further, substantial new developments will be implemented into an existing variation inversion system. The work proposed in GEOS-CARB will implement and adapt various modeling and analysis tools, linking them closely with GEOS-5 systems available in the Global Modeling and Assimilation Office, in order to better exploit NASA s carbon-relevant observations for monitoring and understanding the global carbon cycle. The development work will leave NASA with enhanced modeling and analysis tools for carbon-cycle monitoring using space-based observations. These tools will be used to address some of the research questions that have arisen in the course of CMS FPP, with a strong emphasis on characterizing uncertainty in CO2 flux computations.

Keywords:

Project Associations:

- NASA CMS

Spatial Extents of Study:

- US

CMS:

- Land-Atmosphere Flux
- Ocean-Atmosphere Flux
- Global Flux

Participants:

David Baker, CIRA Colorado State Univ.
Stephan (Randy) Kawa, NASA GSFC
Christopher (Chris) O'Dell, Colorado State University
Tomohiro (Tom) Oda, Colorado State University and NOAA Earth System Research Lab
Steven Pawson, NASA GMAO
Andrew Schuh, Colorado State University

Project URL(s): None provided.

Research Contributions:

Contribution	**Available by:**
Product Title: net CO2 flux and uncertainties	
Description: • **Objective:** Enhance existing variational data assimilation system for estimating time-varying net CO2 fluxes at the surface. Investigating the use of a weak dynamical constraint and estimating satellite bias parameters as part of the flux inversion. Assess the accuracy of the low-rank covariance produced by the variational method by comparing it to that given by a stochastic simulation technique (an 'OSSE').	

- **Inputs/Data products used:** GOSAT xCO2
- **Algorithm/Name of models used:** Variational carbon data assimilation system (4D-Var) solving for CO2 fluxes on a global domain; PCTM off-line atmospheric tracer transport model; CASA and LPJ land biosphere models to provide prior and truth for the land regions.
- **Spatial Domain:** Global
- **Time Period:** 2009-2013
- **Evaluation:** in situ CO2 measurements at surface and from aircraft, land-based column CO2 measurements from TCCON, etc
- **Intercomparison efforts/gaps:** Sander Houweling is conducting an intercomparison of satellite-based CO2 inversions under the aegis of the Transcom project.
- **Uncertainty estimates:** The 4DVar inversion method produces a low-rank covariance estimate. This will be compared to a better estimate of the covariance produced by a GOSAT OSSE study to assess the scales for which it may be useful.
- **Uncertainty categories:** Both deterministic and ensemble

Expected Users:
Metadata URL(s):
Data Server URL(s):

Publications: None provided.

Saatchi-02 (2012)

Project Title: Prototyping MRV Systems Based on Systematic and Spatial Estimates of Carbon Stock and Stock Changes of Forestlands

Science Team Members:
Sangram Ganguly, NASA ARC BAERI
Nancy Harris, Winrock International
Ramakrishna (Rama) Nemani, NASA ARC
Sassan Saatchi, CALTECH/JPL (**Project Lead**)

Abstract: Under phase I of the Carbon Monitoring System (CMS) Biomass Pilot Project, we developed a map of aboveground carbon stocks at 100-m spatial resolution using a combination of remote sensing products combined with ground inventory data. In phase II, we propose to build upon phase I by developing similar spatial products for carbon stocks in all pools (belowground biomass, dead wood, forest floor, soil organic carbon) for three points in time so that net annual carbon stock changes (fluxes) over time may be estimated spatially over US forestlands. Additionally, we propose to test a methodology for separating net flux into its component parts of gross emissions and gross removals to enable a better understanding of how forests should be managed to decrease emissions and increase removals. We will use remote sensing products to quantify areas of forest disturbance and change and develop a fully spatial framework for estimating GHG dynamics (i.e., gross emissions and removals). Our proposed methodology will follow the IPCC Good Practice Guidelines for national GHG accounting from the forest/land-use sector. The expected spatial framework will enable future integration of the proposed activities and products with the CMS Flux Pilot Project. It will also demonstrate a method by which spatial data and models can be integrated with ground data to prototype IPCC recommended Monitoring, Reporting and Verification (MRV) systems for reducing

emissions from deforestation and forest degradation and increasing removals from enhancement of forest carbon stocks.

Keywords:

Measurement Approaches:

- Remote Sensing
- In Situ Measurements
- Modeling

Science Questions:

- Prediction
- Decision Support

Project Associations:

- NASA CMS

Interim Synthesis:

- Regional-Continental

Spatial Extents of Study:

- US

CMS:

- Land Biomass
- Land-Atmosphere Flux
- MRV

Other Keywords: Forest Biomass, Biomass Change, Carbon Pools, GHG, MRV

Participants:

Richard Birdsey, USDA Forest Service
Sandra Brown, Winrock International
Andrew (Andy) Finley, Michigan State University
Alexander Fore, JPL
Sangram Ganguly, NASA ARC BAERI
Stephen (Steve) Hagen, Applied Geosolutions
Nancy Harris, Winrock International
Kristofer (Kris) Johnson, USDA Forest Service
Ramakrishna (Rama) Nemani, NASA ARC
Sassan Saatchi, CALTECH/JPL
Christopher (Chris) Woodall, USDA Forest Service
Yifan Yu, UCLA

Project URL(s):

http://carbon.jpl.nasa.gov/
http://carbon.nasa.gov/

Research Contributions:

Contribution	**Available by:**
Product Title: Carbon pools (AGB,BGB,CWD,forest floor,soil),Net carbon stock changes (fluxes), Disturbance Layers (time since disturbance, recovery rate, disturbance severity),	

Description:

- **Objective:** The objectives of this proposal respond to the CMS solicitation call to â€œExtend, enhance, or evolve the current pilot products (i.e., biomass and flux products) using either the current methodological approach(es) or an alternative approach(es) to producing the product(s)â€. We propose to evolve the CMS-BPI into a spatial approach for quantifying GHG emissions and removals (or sources and sinks) by focusing on the following three main objectives:
  1) Spatially represent all carbon pools (AGB, BGB, CWD, forest floor, soil) in forestlands of the United States by integrating remote sensing and GIS techniques with the US forest inventory data
  2) Develop a systematic and spatially refined estimate of net forest carbon stock changes (i.e., fluxes) between 2000 and 2010 that can be compared to net fluxes derived using the extensive network of FIA plots
  3) Develop and prototype an MRV system that tracks emissions and removals of carbon

separately to be used for international policy applications with the capability of providing national or sub-national scale baselines of gross and net carbon fluxes and uncertainty, and test its applicability to the State of Alaska, where a GHG inventory is sorely lacking

- **Inputs/Data products used:** GLAS, FIA, Landsat LAI, MODIS VI/ Reflctance, NLCD, Radar, USFS Carbon Pool,
- **Algorithm/Name of models used:** Maxent, Leaf Area Index Radiative Transfer Model, Radar Backscatter Model
- **Spatial Domain:** CONUS + Alaska
- **Time Period:** 2005-2010
- **Evaluation:**
- **Intercomparison efforts/gaps:**
- **Uncertainty estimates:** Produce error propagation and uncertainty analysis for all carbon stock and stock change calculations. The bootstrapping approach to uncertainty assessment will be used. Estimate statistical uncertainty bounds associated with the final forest carbon stock and change estimates using a randomized, Monte Carlo-style sampling technique. The bootstrapping will be performed on each individual model component used in generating the gridded forest carbon estimates. The major individual model components for which we will conduct this procedure include: (a) the allometry models relating forest structure to biomass (USFS-FIA); (b) the model relating FIA estimated above-ground biomass to the remotely sensed observations; (c) the relationship between above and below-ground biomass (USFS-FIA); (d) the spatial modeling for extrapolating litter, CWD, and SOC; and (e) the model for estimating forest loss/recovery from remote sensing observations.
- **Uncertainty categories:** ensemble

Expected Users:

Metadata URL(s):

Data Server URL(s):

http://nacp-files.nacarbon.org/biomass_pilot/JPL_ARC_Maps/

Publications: None provided.

4th NACP All-Investigators Meeting Posters:

- Estimation of Aboveground Biomass at a High Spatial Resolution Using an Extensive Data Record of Satellite Derived Metrics: A Case Study with California -- (*Sangram Ganguly*, Gong Zhang, Ramakrishna R. Nemani, Sassan Saatchi, Cristina Milesi, Michael White, Yifan Yu, Alexander Fore, Weile Wang, Petr Votava, Ranga B. Myneni) [abstract]
- Decision Support and Robust Estimation of Uncertainty in Carbon Stocks and Fluxes -- (*Stephen Hagen*, Nancy Harris, Sassan Saatchi, William A. Salas, Sangram Ganguly, Christopher W. Woodall) [abstract] [poster]

Shuchman-01 (2012)

Project Title: Development of New Regional Carbon Monitoring Products for the Great Lakes Using Satellite Remote Sensing Data

Science Team Members:
Gary Fahnenstiel, Michigan Technological University
Robert (Bob) Shuchman, Michigan Technological University (**Project Lead**)

Abstract:
The Great Lakes represent approximately 20% of Earth's surface freshwater and are the largest surface area of freshwater on the planet. Understanding the magnitude of the contribution that the Great Lakes make to Earth's carbon budget is important to regional, national, and international carbon monitoring efforts. Quantifying the annual carbon fixation for each of the five Great Lakes as well as determining which of the Lakes are carbon sinks versus sources will be a significant contribution to the overall understanding of the Earth's carbon budget. Despite the large number of in situ based productivity measurements made at selected locations and limited times during the year in the Great Lakes, a strong case can be made that accurate annual lake-wide estimates of primary production do not exist for any of the Great Lakes. Thus, a new approach using satellite data is needed to provide truly lake-wide primary production in these important large ecosystems. This proposed satellite based program will result in new regional carbon monitoring products that will characterize each Laurentian Great Lake's annual carbon fixation and additionally address whether each Great Lake is a net source or sink of carbon. This will be accomplished through characterization of phytoplankton primary production (PP) using a new Great Lakes Primary Productivity Model (GLPPM). The GLPPM utilizes NASA OceanColor satellite imagery (MODIS, VIIRS). Additionally, aggregating annual PP for all five lakes will give insight into whether the Great Lakes are as a whole is a source or sink of carbon and to determine the significance of the Great Lakes to Earth's total carbon budget. Individual Great Lakes annual carbon production information will also be invaluable input into high resolution regional carbon models. A key element to the success of this program includes additional field measurements in Lakes Superior, Michigan, Huron and Great Lakes embayments. These in situ observations will be used to better quantify carbon fixation rates that are key to producing accurate carbon estimation products. Additionally the field data will aid in the product accuracy assessment. In summary, monthly and annual carbon production products for each of the five Great Lakes generated under this program will be provided to stakeholders via an active data sharing program within NOAA/Great Lakes Environmental Research Lab (GLERL) and the Great Lakes Observing System (GLOS). A key to providing this valuable data for decision makers, scientists, the public, and other stakeholders will be rigorous error quantification and accuracy assessment.

Keywords:

Project Associations:
- NASA CMS

Spatial Extents of Study:
- US

CMS:
- Lake Biomass
- Ocean Biomass
- Ocean-Atmosphere Flux

Participants:
Gary Fahnenstiel, Michigan Technological University
Robert (Bob) Shuchman, Michigan Technological University

Project URL(s):
None provided.

Research Contributions:

Contribution	**Available by:**
Product Title: Monthly and annual lake-wide primary production estimates for all five Great Lakes	
Description: • **Objective:** Develop new satellite-derived primary production estimate for Great Lakes. Conduct historical analysis of primary production and key input parameters, i.e., chlorophyll, KdPAR, and PAR. • **Inputs/Data products used:** Oceancolor Satellite data, carbon fixation rate data	

- **Algorithm/Name of models used:** Great Lakes Primary Production Model (GLPPM)
- **Spatial Domain:** Great Lakes Region
- **Time Period:** 1979-1987 and 1997-present
- **Evaluation:** NOAA GLERL in situ monitoring data
- **Intercomparison efforts/gaps:** Comparisons to lakes Michigan, Huron and Superior measurements and other Great Lakes observations.
- **Uncertainty estimates:** Preliminary evaluation of errors will be made with comparisions to observations. Pixel level uncertainty and production model uncertainty will be evaluated with Monte Carlo simulation and modeling.
- **Uncertainty categories:** model-data comparison

Expected Users:
Metadata URL(s):
Data Server URL(s):

Publications: None provided.

Verdy-01 (2012)

Project Title: Towards a 4D-Var Approach for Estimation of Air-Sea Carbon Dioxide Fluxes

Science Team Members: Robert (Bob) Key, Princeton University
Ariane Verdy, Scripps Institution of Oceanography (**Project Lead**)

Abstract: The challenge- Any Carbon Monitoring System (CMS) must account for fluxes of carbon between the atmosphere and the oceans, the world s largest reservoir of carbon dioxide (CO2). Currently, air-sea CO2 flux estimates are produced by sophisticated physical-biogeochemical models. However, these models still fail to represent significant patterns in the observed fluxes, and these discrepancies are thought to be largely due to errors in the simulation of biogeochemical processes. Our goal- This proposal capitalizes on two recent developments in oceanography to lay the groundwork for a global ocean CMS with improved biogeochemistry. Satellite measurements of the surface ocean and sensor-based measurements of the interior ocean are rapidly increasing the temporal and spatial coverage of biogeochemical data. Simultaneously, the development of four-dimensional variational assimilation (4D-Var) modeling has combined the forward modeling and traditional static inversion approaches to overcome the primary limitations of both: forward models estimate what could have happened in the ocean rather than what actually happened, and inversions cannot yield predictions. The 4D-Var approach automates the process of adjusting initial conditions and model parameters to produce an optimal fit of the model to physical constraints and all available observations. Our vision is of a state-of-the-art global physical-biogeochemical ocean model that incorporates data from the growing global network of satellites, sensors, and shipboard measurements to improve its estimates of air-sea CO2 fluxes. Our contribution- We will provide the missing components for 4D-Var physical-biogeochemical assimilation. As we build toward our goal of a global model-observation synthesis, each step of the proposed research will generate independently valuable scientific products: 1. We will test the efficacy of extending the 4D-Var approach to biogeochemistry by using it to optimize both the idealized biogeochemical and physical state of an eddy-resolving model of the California Current Ecosystem (CCE) for 2007-2011. The model will be optimized by adjusting the initial conditions, boundary conditions, external forcing, and parameter values to reduce the misfit between the model and the dense and diverse observations (including in situ measurements of carbon, oxygen, phosphate, pH, and

alkalinity) available of the CCE during this time period. 2. We will further develop the biogeochemical component of the model to allow assimilation of satellite-based chlorophyll estimates and to improve the representation of other constraints, and optimize this new implementation of the physical-biogeochemical model to improve our estimate of air-sea CO2 fluxes in the CCE. 3. We will extend the data-processing of hydrographic observations to produce a self-consistent dataset of the quality, richness of properties, and temporal extent that will be required to constrain a global 4D-Var biogeochemical model. GLODAPv2 (GLobal Ocean Data Analysis Project version 2) will be a calibrated unification of existing biogeochemical data products and new data over the period 1972-2011. As more observations become available, state estimation is undoubtedly the way forward for addressing the objectives of NASA's CMS by bringing together observations and modeling tools to generate accurate high-resolution and time-varying maps of air-sea CO2 fluxes. Together, the development of 4D-Var methods and the observational dataset will enable global model-observation syntheses of the ocean carbon cycle over climate-relevant time scales.

Keywords:

Project Associations:

- NASA CMS

Spatial Extents of Study:

- US

CMS:

- Ocean-Atmosphere Flux

Participants:

Brendan Carter, Princeton University
Robert (Bob) Key, Princeton University
Matthew Mazloff, Scripps Institution of Oceanography
Jorge Sarmiento, Princeton University
Ariane Verdy, Scripps Institution of Oceanography

Project URL(s):

http://sose.ucsd.edu/CASE/
http://cdiac.ornl.gov/oceans/glodap/

Research Contributions:

Contribution	**Available by:**
Product Title: Ocean biogeochemistry dataset (GLODAPv2)	

Description:

- **Objective:** Compile a calibrated dataset of in situ ocean observations, such as required to constrain a global 4D-Var biogeochemical model
- **Inputs/Data products used:** Available high quality shipboard data from 1973-present provided by the global research community
- **Algorithm/Name of models used:**
- **Spatial Domain:** Global ocean
- **Time Period:** 1973-2012
- **Evaluation:**
- **Intercomparison efforts/gaps:** GLODAPv1, CARINA, PACIFICA
- **Uncertainty estimates:** measurement accuracy is generally determined by simultaneous analysis of primary or secondary standards of known concentration

- **Uncertainty categories:** data-data comparison

Expected Users:

Metadata URL(s):

Data Server URL(s):

http://cdiac.ornl.gov/oceans/

http://cchdo.ucsd.edu/

Contribution	**Available by:**

Product Title: Regional high-resolution air-sea CO2 flux

Description:

- **Objective:** Develop the methodology for 4D-Var data assimilation in a coupled physical-biogeochemical ocean model, to improve the estimation of air-sea co2 fluxes
- **Inputs/Data products used:** Satellite: Altimeter SSH (Jason1-2, TOPEX), Microwave SST, Ocean Color (MODIS), In Situ temperature, salinity, biogeochemistry
- **Algorithm/Name of models used:** BLING implementation in MITgcm
- **Spatial Domain:** California coastal ocean
- **Time Period:** 2007-2011
- **Evaluation:** Adjoint model evaluation of the cost function (misfit between observations and model)
- **Intercomparison efforts/gaps:**
- **Uncertainty estimates:** We will quantify the consistency of the model with available observations
- **Uncertainty categories:** model-data comparison

Expected Users:

Metadata URL(s):

Data Server URL(s):

Publications: None provided.

West-03 (2012)

Project Title: Estimating Global Inventory-Based Net Carbon Exchange from Agricultural Lands for Use in the NASA Flux Pilot Study

Science Team Members: Tristram (Tris) West, Joint Global Change Research Institute (**Project Lead**)

Abstract: Inventory-based estimates of C flux have been developed for US agriculture (West et al. 2011), US forests (Zheng et al. 2011 and McKinley et al. 2011), and for North American agriculture and forest lands (Hayes et al. 2012). These estimates combine C uptake, harvest and removal, and C release to generate regional C flux estimates. These estimates differ from carbon biomass or stock estimates which often only represent the net C uptake component of the flux. The inventory-based C flux method of estimation has evolved over the past 5 years, as noted by the recent aforementioned citations, and has been used successfully as input to biogeochemical models, atmospheric transport models, and economic models. Estimates have also been used as independent data sets for comparison with other methods (King et al. 2012). The usefulness of this new method is evident. What is needed now is an expansion of the method for global use. The purpose of this proposed research is to develop a global C budget for agricultural carbon uptake and release, as was done for the US by West et al. (2011). A global US C budget, together with satellite remote sensing of land cover, will provide a gridded global C flux for agricultural lands. This product can be used as input to the NASA Flux Pilot Study and by models currently engaged in the Study. The proposed method combines aforementioned methods of spatially explicit C uptake and release with a NASA-generated global data set on human consumption of agricultural commodities (Imhoff et al. 2004, 2006) for use in the CASA model (Potter et al. 1993, Williams et al. 2012) and other Pilot Study models. Datasets generated will also be commensurate with those used in the DOE Integrated Assessment (IA) program, which allows for future economic projections of land use and human population to be linked with carbon fluxes generated with NASA models.

Keywords:

Measurement Approaches:
- Remote Sensing
- Modeling
- Synthesis

Science Questions:
- Diagnosis
- Attribution

GHG Compounds:
- Carbon Dioxide

Project Associations:
- NASA CMS

Spatial Extents of Study:
- Global
- US

CMS:
- Land Biomass
- Land-Atmosphere Flux
- Decision Support

Other Keywords: emperical, inventory-based estimates of net carbon exchange from global agricultural systems

Participants:
Varaprasad Bandaru, PNNL
George (Jim) Collatz, NASA GSFC
Marc Imhoff, Joint Global Change Research Institute
Tristram (Tris) West, Joint Global Change Research Institute
Julie Wolf, UMD-ESSIC

Project URL(s): None provided.

Research Contributions:

Contribution	**Available by:**
Product Title: Geospatial estimates of carbon uptake and release of crop-derived carbon	
Description: • **Objective:** Develop a global gridded dataset for cropland carbon fluxes, based on global- and country-level inventory data on crop yields	

- **Inputs/Data products used:** MODIS PFT v5.1 land cover
- **Algorithm/Name of models used:**
- **Spatial Domain:** Global ocean
- **Time Period:** 2009-2011
- **Evaluation:**
- **Intercomparison efforts/gaps:** Inherent intercomparison with inventory and MODIS data
- **Uncertainty estimates:** A range of values have been collected in a meta-analysis for each parameter used in estimating crop growth and associated carbon content. These values will be used to generate PDFs which will constitute the monte carlo analysis.
- **Uncertainty categories:** ensemble

Expected Users:
Metadata URL(s):
Data Server URL(s):

Contribution	**Available by:** Jan 2014
Product Title: Gridded global agricultural carbon flux	
Description: Gridded global data for cropland NPP, harvested biomass, and ultimate emissions from livestock and people.	
Expected Users: Global or regional models with needs to improve agriculture biomass estimates, the amount of biomass removed from the field vs remaining as residue, and the approximate location of cropland carbon release.	
Metadata URL(s):	
Data Server URL(s): http://daac.ornl.gov/	
Site(s) of Data Collection: 0.00000,-0.00000	

[view google map]

Publications: None provided.

Brown-01 (2013)

Project Title: Applications of the NASA Carbon Monitoring System: Engagement, Use, and Evaluation

Science Team Members: Molly Brown, NASA GSFC (**Project Lead**)
Vanessa Escobar, Sigma Space Corp.

Abstract: This proposal provides a scope of work for studying and engaging with the user community for the NASA Carbon Monitoring System (CMS) pilot projects. Under the CMS initiative, NASA will be developing end-to-end expertise on regional, national and international carbon monitoring products based on satellite remote sensing. In this proposal, we focus on understanding and engaging the science and user community of these products to enable improved characterization of CMS products, preparation for eventual data delivery, and evaluate the CMS products that have been developed. The focus of this activity is to evaluate current and planned NASA CMS products with regard to their use in specific decision making contexts. This effort is aligned with the mission of the Carbon Cycle Science program to leverage NASA investments to discover and demonstrate applications that inform resource management, policy development, and decision making within operational agencies responsible for resource management and policy decisions that affect carbon emissions, sequestration, and fluxes among terrestrial, aquatic, and atmospheric environments. Our proposed research is highly relevant to the following activities listed as a priority for this NRA: Studies of stakeholder interests and requirements that offer to 1) understand and engage the user community for carbon monitoring products and/or 2) evaluate current and planned NASA CMS products with regard to their value for decision making by these users. The effort is designed to identify and engage with the user community for carbon monitoring products and to ensure that every scientist working within CMS has exposure to these users. Determining the requirements of the broader decision making community is a critical element of an effective applications program. We will work to find policy and practical users of CMS products for the atmosphere, ocean, and land. We will express the needs of the community to the CMS SDT and the broader CMS science community to help guide product development. Thus, we will develop a path that illustrates the connection between the user needs, the CMS product and the decision and policy frameworks that link the science to society. In order to foster this interplay between science capabilities and user needs via CMS product development and product application in decision-making environments, we have three broad objectives: 1) Develop communication strategies that link directly to the goals, objectives and accomplishments of the NASA CMS program and build a broad support system for CMS science PIs through transparent and inclusive processes involving scientists and end users; 2) Identify group(s) of institutions and organizations who become 'early adopters' of NASA CMS products. Selected early adopters will have an immediate use for the CMS product(s) and have clearly identified requirements for existing and planned NASA CMS scientific output; and 3) Evaluate the current and planned NASA CMS products, and determine the degree to which this proposed CMS Applications program has met success criteria.

Keywords:

Project Associations:

- NASA CMS

Spatial Extents of Study:

- US

CMS:

- Land Biomass
- Land-Atmosphere Flux
- Decision Support

Participants:
Molly Brown, NASA GSFC
Sabrina Delgado Arias, Sigma Space
Vanessa Escobar, Sigma Space Corp.

Project URL(s): None provided.

Research Contributions: None provided.

Publications: None provided.

Cochrane-01 (2013)

Project Title: Filling a Critical Gap in Indonesia's National Carbon Monitoring, Reporting, and Verification Capabilities for Supporting REDD+ Activities: Incorporating, Quantifying and Locating Fire Emissions from Within Tropical

Peat-swamp Forests

Science Team Members: Mark Cochrane, South Dakota State University/GIScCE (**Project Lead**)
Bob Yokelson, University of Montana

Abstract: Project Summary: Because of episodic uncontrolled fires within drained peat-swamp forests, Indonesia is ranked the 4th largest CO2 emitter over the last half century. The former 1 million hectare Mega Rice Project (MRP), designed to convert extensive peat lands into farm lands, is a major emissions source. Deep organic soils storing vast amounts of carbon are now being lost to decomposition and combustion. The 120,000 ha Kalimantan Forests and Climate Partnership (KFCP) Reduced Emissions from Deforestation and forest Degradation (REDD+) project is within the former MRP. In collaboration with the Indonesian government's Forestry Research and Development Agency (FORDA), we will develop a prototype peat-fire emissions module for KFCP to incorporate into the Indonesian National Carbon Accounting System (INCAS). This capacity will enable annual quantification of fire-related emissions. Our research project will utilize Landsat and MODIS data and products to quantify land cover changes, burned area and estimate the timing of fire activity. We will incorporate TRMM data for relating precipitation history to the timing of observed water table changes that impact peat-fire activity at KFCP. We will integrate satellite data with existing aerial KFCP Lidar (2007 & 2010), and propose a repeat Lidar collection during the study to provide quantified temporal topographic change maps to validate our modeled results of fire-related peat consumption. This project will leverage the extensive and ongoing data collection efforts for hydrology, fuels, land uses and fire occurrence at KFCP, with our initial field work and laboratory testing of regional peat combustion and emission characteristics to provide guided field testing of background and fire-related carbon emission rates and types (e.g. methane, CO2, CO, particulates, other) during El Nino and non-El Nino years as available. Through groundbreaking emissions field sampling of in-situ smoldering surface, shallow (<20 cm) and deep (>20 cm) peat fires, with on-site gas chromatography for quantifying reactive species, whole air sampling for precise lab measurements of non-reactive gases, and simultaneous filter sampling of particulates, we will create comprehensive and pertinent emissions factors (EFs) that will be critically important for assessing the health impacts and total global warming potential (GWP) of these emissions. In our interdisciplinary research, we will investigate the chains of social and bio-physical events leading to these deep-peat fires, integrating fire scene analyses with social data to describe when, where, how, and under what conditions fires within KFCP have occurred, so that more effective mitigation strategies can be developed in the future. Accurate accounting of peat-fire carbon emissions requires understanding how their presence, depth of burning, and spread rates relate to the interplay of climate, weather, land use, land cover, drainage status, disturbance history, fire type, peat depth and composition. Modeling this phenomenon requires defining 1) the annual surface area burned, 2) the available fuel fraction (burnable) at each location through time, and 3) the amount of fuel consumed per unit area. We will implement a modeling approach that initially uses existing data on the peat hydrology, climate, land cover, burned area, timing of ignitions and fuel loads to stochastically provide peat fire probability and parameterize depth and area burned from the 2007 Lidar data. This initial model will be used to project the expected area, type, and depth of burning from 2007-2011 and then checked against the 2011 Lidar data set to refine calibration of the modeled parameters. The third modeling phase will provide Monte Carlo estimates of type, depth and area of burning, with emissions quantitatively weighted by appropriate EFs derived for surface, shallow and deep peat smoke amounts that will be validated using the proposed third Lidar data collection.

Keywords:

Project Associations:

- NASA CMS

Spatial Extents of Study:

- US

CMS:

- Land Biomass
- Land-Atmosphere Flux
- MRV

Participants: Mark Cochrane, South Dakota State University/GIScCE
Bob Yokelson, University of Montana

Project URL(s): None provided.

Research Contributions: None provided.

Publications: None provided.

Cohen-02 (2013)

Project Title: An Historically Consistent and Broadly Applicable MRV System Based on Lidar Sampling and Landsat Time-series (Tested in the US, and applied to the US NGHGI reporting system)

Science Team Members:
Hans Andersen, USDA Forest Service, Pacific Northwest Research Station
Warren Cohen, USDA Forest Service (**Project Lead**)
Grant Domke, USDA Forest Service
Gretchen Moisen, US Forest Service
Todd Schroeder, US Forest Service, Forest Inventory and Analysis

Abstract: We focus our attention on the development of a Monitoring, Reporting, and Verification (MRV) accounting system that could be used by developing countries within the context of the United Nations (UN) REDD Programme. Because one system will not fit all needs, we consider different biomass estimation frameworks and different components for inclusion in the system. Design-based inference is commonly applied to a sample field plot network, as it is for the US National Greenhouse Gas Inventory (NGHGI) baseline reporting to the UN Framework Convention on Climate Change (UNFCCC). But field plot networks are expensive to install and maintain. Sampling with lidar strips, supported by a smaller set of plots may be an attractive alternative that is highly relevant to many REDD countries, as is the use of Landsat for disturbance monitoring. Biomass estimation uncertainties associated with use of these different datasets in a design-based inference framework will be examined. We will also develop and test estimators that rely primarily on Landsat data within a model-based inference framework. The contributions from Landsat are the current (e.g., 2013) spectral response and metrics that describe disturbance history derived from a time series leading up to the current date. In this context, either plot data or lidar data can be used to parameterize the model and we will contrast the uncertainty effects of these datasets. A key advantage of the model-based framework is that it can be extended back in time (e.g., to 1990) using a consistent approach. The main feature of the model-based approach is that it relies directly on disturbance history as an indicator of biomass density. Using Landsat spectral data from a given date (e.g., 2000) and disturbance history metrics derived from a time series leading up to that date (e.g., 1984-2000), the statistical model developed for the current period (e.g., 2013) can be applied historically. This is critical because REDD requires a way to estimate biomass historically, back to a baseline year of 1990. For the approach to take maximum advantage of disturbance history metrics to predict biomass density, a sufficient time series length is critical. This requires that we reach back into the MSS archive to develop the disturbance history metrics for the approach to be fully effective in estimating biomass for the 1990 baseline. The US, while not a REDD country, is a party to the UNFCCC and has a need for similar NGHGI baseline information. The various components of our MRV system will be tested in the US, where the best data are available for parsing the uncertainty contributions of the several system components we will test. In doing so, we will develop and test an historical biomass mapping approach that, if implemented, would provide REDD countries a practical set of workflows for integrated monitoring of current and historic baseline carbon stocks and trends, with an understanding of the uncertainties associated with different components of the alternative workflows. Additionally, with the improvements expected from including Landsat-derived disturbance history into the methods used for the US NGHGI, this research would provide NASA and CMS with a collaborative roll in the process of reporting US forest carbon estimates to the UNFCCC.

Keywords:

Project Associations:
- NASA CMS

Spatial Extents of Study:
- US

CMS:

- Land Biomass
- MRV

Participants:

Hans Andersen, USDA Forest Service, Pacific Northwest Research Station
Warren Cohen, USDA Forest Service
Grant Domke, USDA Forest Service
Gretchen Moisen, US Forest Service
Todd Schroeder, US Forest Service, Forest Inventory and Analysis

Project URL(s): None provided.

Research Contributions:

Contribution	**Available by:**
Product Title: Maps and estimates of disturbance and aboveground biomass.	

Description:

- **Objective:** Create current aboveground live biomass maps and estimates that integrate a selection of spatially- and temporally-coincident FIA plots, lidar samples, and Landsat imagery, with Landsat-derived disturbance history metrics. Map and estimate historic live biomass from the current period back to 1990. Improve the existing US NGHGI approach to estimate live biomass consistently through time for each year from the current period back to 1990.
- **Inputs/Data products used:** FIA field plots, airborne lidar, Landsat time series
- **Algorithm/Name of models used:**
- **Spatial Domain:** Six Landsat scenes in different forested regions of the conterminoud US
- **Time Period:** 1990-2014
- **Evaluation:**
- **Intercomparison efforts/gaps:**
- **Uncertainty estimates:** Biomass estimates derived using different estimation frameworks and different input datasets will impact uncertainty in ways that will be explicitly examined. A design-based framework, using plots alone (as for the US NGHGI), is a standard approach against which to contrast all other results. For current biomass, incorporating lidar strip samples with plots will yield a separate set of results, as will incorporation of biomass maps from Landsat. All of these design-based approaches will be contrasted against a strictly model-based mapping approach that is not solely dependent on the sample plots for the underlying estimation structure. This is important in the REDD context because model-based approaches may be needed for those countries who have yet to establish an NFI that would allow design-based inference and model-based inference will be required for historic estimation of biomass. Because model-based inference is dependent on specification of an appropriate model, the methods developed will include specifying how model assumptions can be verified. Effects of poor-precision GPS coordinates will be tested, as will the accuracy of history metrics derived from different disturbance maps v. those derived from TimeSync, and those derived with and without the use of MSS data to extend the time series. In the context of the US NGHGI, in addition to the inclusion of disturbance history, we will test the effects of including high-quality observations of land use

change, and of disturbance maps for stratification.

- **Uncertainty categories:** ensemble; model-data comparison

Expected Users:
Metadata URL(s):
Data Server URL(s):

Publications: None provided.

Collatz-02 (2013)

Project Title: Improving and extending CMS land surface carbon flux products including estimates of uncertainties in fluxes and biomass

Science Team Members: George (Jim) Collatz, NASA GSFC (**Project Lead**)

Abstract: This proposal addresses the Studies to improve the characterization and quantification of errors and uncertainties in existing and/or proposed NASA CMS products, including errors and uncertainties in the algorithms, models, and associated methodologies utilized in creating them; component of CMS call for proposals. Our team was originally funded in Phase I of the CMS project to provide land surface carbon fluxes (NPP/GPP, RH/RE, Fire from CASA-GFED3) for the period 2009-2010. We produced these products, evaluated them against other models and contributed to the interpretation of modeled atmospheric CO2 distributions produced by GSFC's GEOS-5 transport model and the source/sink distributions produced by JPL's atmospheric inverse model. Our data products are available on the CMS website. For Phase II, we did not seek funding support but contributed to the Pawson and Bowman projects as collaborators providing fluxes for 2011 and further evaluation of those. Our data products are well suited for use by other CMS projects because they are highly constrained by satellite observations and have a long history of evaluation by the atmospheric CO2 modeling community. There is the need for continued updates of these key land data products and for estimates of uncertainties which were not previously supplied. For this proposed work we plan to produce land carbon fluxes for 2012 from CASA-GFED3 by the end of this calendar year. In subsequent years of the proposal we will introduce the new updated version of the model (CASA-GFED4) with improved physiological and fire parameterizations, improved burned area estimates including representation of smaller fires, and finer spatial resolution (1/4 degree) extending the time series into the future with a latency of ~5 months. We have begun preliminary uncertainty analyses of the CASA-GFED3 fluxes by first testing the sensitivity of the modeled fluxes to characteristic model parameters. From the sensitivity analyses we are selecting a number of key parameters and using published and expert opinion estimates of uncertainties in these parameters to estimate flux uncertainties using a Monte Carlo method. We will estimate uncertainties in the individual fluxes (NPP, RH, fires, NBP, GPP, RE) at monthly time steps for the entire period of the data set. Quantified flux uncertainties are critically needed by the CMS atmospheric modeling groups for their estimates of overall uncertainties in surface carbon sources and sinks. Our simulations also produce global biomass estimates at the model's native resolution with uncertainties. We plan to evaluate these estimates against others including the CMS Biomass products.

Keywords:

Project Associations:

- NASA CMS

Spatial Extents of Study:

- US

CMS:

- Land-Atmosphere Flux

Participants: George (Jim) Collatz, NASA GSFC

Project URL(s): None provided.

Research Contributions:

Contribution	Available by:
Product Title: GPP/NPP, RE/RH, and fire emissions	

Description:

- **Objective:** We produce and update global terrestrial carbon fluxesat monthly to 3hrly time steps and 0.5 degree to ~1 degree spatial scales respectively. data are available from 2003 to 2012 now and will include 2013 and 2014 by the end of phase 2b. fluxes are derived from CASA-GFED3 model.
- **Inputs/Data products used:** MERRA meteorology, GIMMS NDVI, MODIS Burned area
- **Algorithm/Name of models used:** CASA-GFED
- **Spatial Domain:** global land
- **Time Period:** 2003-2014
- **Evaluation:** surface and column atmospheric CO2, fluxes from atmospheric inversions, eddy covariance fluxes, independent biomass estimates
- **Intercomparison efforts/gaps:**
- **Uncertainty estimates:** influence of parameter uncertainty using monte carlo ensemble. uncertainties estimated from model-data comparisons (surface and column co2, eddy covariance fluxes, inversions, independent biomass estimates).
- **Uncertainty categories:** ensemble, model-model, and model-data comparisons

Expected Users:

Metadata URL(s):

Data Server URL(s):

http://nacp-files.nacarbon.org/nacp-kawa-01/

http://carbon.nasa.gov/cgi-bin/cms/inv_pgp.pl?pgid=581#datasection

Publications: None provided.

Dubayah-04 (2013)

Project Title: Development of a Prototype MRV System to Support Carbon Ecomarket Infrastructure in Sonoma County

Science Team Members:
Ralph Dubayah, University of Maryland (**Project Lead**)
Anuradha (Anu) Swatantran, UMD
Maosheng Zhao, University of Maryland

Abstract: National and international programs have an increasing need for precise and accurate estimates of forest carbon and structure to support greenhouse gas reduction plans, climate initiatives, and other international climate treaty frameworks such as REDD++. Central to these activities is the development of MRV (measurement, reporting and verification) systems that provide an accounting of forest carbon emission and sequestration at high spatial resolution with appropriate temporal frequencies. Such systems can be used to

support and sustain the development of an 'ecomarket' infrastructure centered on carbon, along with other ecosystem services, such as biodiversity, water resources, and the like. Central to ecomarkets is the creation of financial incentives that reward the preservation and enhancement of ecosystem services through time, as enabled from robust MRV systems. NASA has recognized the urgent need for the development of MRV through its initiation of the Carbon Monitoring System (CMS) program. The University of Maryland, working with NASA centers, the USFS, and commercial entities has led research efforts in Phase I and Phase II that have laid the basic groundwork for MRV. Our Phase II project uses existing, wall-to-wall airborne lidar coverage and in-situ field data collection to produce high-resolution maps of carbon stocks for all of Maryland. These same data are also used to drive a prognostic ecosystem model to predict carbon fluxes and carbon sequestration potential. This work has demonstrated the feasibility of large-scale mapping using airborne lidar, an important first step, and suggests logical follow-on activities that should be undertaken towards the realization of operational MRV systems that are responsive to local, national and international interests in management and policy. The overall goal of this project is the continuing development of a prototype MRV system based on commercial off-the-shelf (COTS) remote sensing and analysis capabilities to support ecomarket infrastructure in Sonoma County, California. Building on our East Coast county-level work as part of CMS I and CMS II, we seek to address the following questions: - What accuracies are achievable using predominantly COTS-based approaches to high-resolution MRV for forest carbon? - What is the 'price-of-precision' for MRV systems and how does this vary as a function of sample design, ground data, remote sensing data acquisition and analysis costs? - How can stakeholder needs and requirements be integrated during the creation and implementation of MRV systems to provide effective decision support and compliance capabilities, and with better-informed policy decisions? Can a cloud-based architecture be used to facilitate the initiation and use of MRV systems to enable their implementation domestically and abroad? We have identified five objectives to answer our research questions: (1) Integration of Sonoma County stakeholder needs and requirements into the MRV system design. (2) High-resolution wall-to-wall estimation of carbon stocks and their uncertainties for Sonoma County and mapping of sequestration potential under various development scenarios using the Ecosystem Demography model. (3) Development of the key components of an end-to-end MRV system that includes data acquisition, warehousing, baseline quantification, data accessibility, accounting, reporting and stakeholder communication. (4) Analysis of the 'price-of-precision' through a cost-benefit analysis of data resolution relative to accuracy achievable at particular spatial scales e.g. United Nations Framework Conference on Climate Change (UNFCCC) Tier 1 vs. Tier 3. (5) Demonstration of a functional prototype MRV platform with visualization, and analytical capabilities for addressing Sonoma County initiatives. Our basic approach to high-resolution carbon stock mapping has been established in our CMS Phase 1 (two Maryland counties) and Phase 2 (23 Maryland counties) efforts.

Keywords:

Project Associations:

- NASA CMS

Spatial Extents of Study:

- US

CMS:

- Land Biomass
- MRV

Participants:

Ralph Dubayah, University of Maryland
Anuradha (Anu) Swatantran, UMD
Maosheng Zhao, University of Maryland

Project URL(s): None provided.

Research Contributions: None provided.

Publications: None provided.

Dubey-01 (2013)

Project Title: Off-the-shelf Commercial Compact Solar FTS for CO2 and CH4 Observations for MRV

Science Team Members: Manvendra Dubey, Los Alamos National Laboratory (**Project Lead**)

Abstract: Monitoring, reporting and verification (MRV) of natural sources and sinks and anthropogenic emission of carbon dioxide (CO2) and methane (CH4) are crucial to predict climate change and develop transparent accounting policies to contain climate forcing. Remote sensing technologies are beginning to monitor CO2 and CH4 from ground and space using high-resolution solar spectroscopy enabling direct MRV. However, the current ground based coverage is very sparse due the need for large and expensive high-resolution spectrometers that limits our MRV abilities, both regionally and globally. There are striking monitoring gaps in Asia (China and India), South America and Africa where the CO2 emissions are growing and there is a large uncertainty in fluxes from land use change and biomass burning. Our project will evaluate the precision, accuracy and stability of new off-the-shelf commercial, compact, affordable and easy to use low-resolution spectrometers by comparing with the much larger high-resolution spectrometers used to monitor CO2 and CH4. While initial results are promising our study will encompass real world conditions and challenges. If we are successful the new off-the-shelf spectrometers will dramatically expand the coverage of regional column CO2 and CH4 observations, particularly in gap regions in the developing world. This will enable transparent and reliable MRV that would put carbon cycle science and carbon trading and put climate treaty verification on a firm foundation.

Keywords:

Project Associations:

- NASA CMS

Spatial Extents of Study:

- US

CMS:

- Land-Atmosphere Flux
- MRV

Participants: Manvendra Dubey, Los Alamos National Laboratory

Project URL(s): None provided.

Research Contributions: None provided.

Publications: None provided.

Duren-01 (2013)

Project Title: Understanding user needs for carbon monitoring information

Science Team Members: Riley Duren, NASA JPL (**Project Lead**)
Kevin Gurney, Arizona State University
Molly Macauley, Resources for the Future
Sassan Saatchi, CALTECH/JPL
Christopher (Chris) Woodall, USDA Forest Service

Abstract: The objectives of the proposed work are to: 1) engage the user community and identify needs for policy-relevant carbon monitoring information, 2) evaluate current and planned NASA Carbon Monitoring System data products with regard to their value for decision making, and 3) explore alternative methods for visualizing and communicating carbon monitoring information and associated uncertainties to decision makers and other stakeholders. We will establish a framework that facilitates frequent and sustained engagement of carbon policy and management stakeholders to define requirements for CMS data products. Our team will work with the CMS science team to acquire prototype data products and help stakeholders evaluate the utility and relevance for policy planning and decision support. We will develop a Carbon Caculator and Data Portal that integrates multiple CMS products to enable those evaluation efforts. Where necessary we will explore new approaches for presenting the results of CMS data products and their uncertainties to decision-makers, again with the intent of helping to inform future CMS requirements and

improve relevance of the ultimate data products. Our team combines experts in carbon management and policy from a representative cross-section of stakeholders in the US government (including the State Department's Bureau of Oceans and International Environment and Scientific Affairs (OES), the Environmental Protection Agency (EPA), and the White House Council on Environmental Quality (CEQ) with other experts working at the interface of science and policy for carbon monitoring (co-investigators from JPL, RFF, ASU, and USFS). The team will meet regularly and share information through a flexible web portal that leverages emerging tools for visualizing data. We will apply the above process to study a range of representative policy scenarios. Examples of topics that may be explored include but are not limited to: policies and management efforts focused on: 1) Land Use, Land Use Change, and Forestry (LULUCF) fluxes for the United States and/or selected developing countries (e.g., Indonesia), 2) Forest carbon stocks and disturbances for the US and/or tropical countries or sub-national projects therein, 3) methane (CH4) emissions from major shale gas basins in the US, and 4) fossil fuel CO2 and CH4 emissions from cities and industrialized states and provinces (including potential linked sub-national carbon emissions trading systems).

Keywords:

Project Associations:

- NASA CMS

Spatial Extents of Study:

- US

CMS:

- Land Biomass
- Land-Atmosphere Flux
- Decision Support

Participants:

Riley Duren, NASA JPL
Kevin Gurney, Arizona State University
Molly Macauley, Resources for the Future
Sassan Saatchi, CALTECH/JPL
Christopher (Chris) Woodall, USDA Forest Service

Project URL(s): None provided.

Research Contributions: None provided.

Publications: None provided.

Graven-01 (2013)

Project Title: Quantifying fossil and biospheric CO2 fluxes in California using ground-based and satellite observations

Science Team Members:

Marc Fischer, Lawrence Berkley National Laboratory
Heather Graven, Scripps Institution of Oceanography (**Project Lead**)
Ralph Keeling, UCSD Scripps Institution of Oceanography
Nick Parazoo, UCLA

Abstract:

This proposal develops a prototype system that combines commercial ground-based measurement techniques with satellite data to address Monitoring, Reporting and Verification (MRV) of regional CO2 fluxes from fossil fuel emissions and biospheric exchange. The system will be centered on the State of California, where it will be responsive to the State's policy measure to reduce greenhouse gas emissions, California's Global Warming Solutions Act (AB-32) which includes a cap-and-trade program, and where a relatively dense measurement network for atmospheric CO2 concentration is already in place. We will use this existing network to conduct field sampling for the measurement of radiocarbon content (D14C) in atmospheric CO2 that will enable us to identify fossil-derived and biospheric-derived CO2 [Turnbull et al. 2006; Graven et al. 2009] at 9 sites across the state. The D14C-based observations of fossil-derived and biospheric-derived CO2, along with measurements of total CO2 concentration from ground-based and satellite platforms, will be analyzed in an atmospheric inversion framework that we will develop from a similar

framework currently being used to estimate emissions of CH4 in California [Jeong et al. 2012; Fischer et al. 2012]. Unique contributions of the proposed work involve the integration of D14C data into an inversion framework to optimize fossil fuel emissions explicitly, and the integration of satellite-derived total column CO2 with ground-based data. The proposed work will also provide evaluation of the natural sink or source of CO2 in California's terrestrial biosphere and evaluation of the biospheric models, CASA-GFED and NASA-CASA, across the widely varying biome types and land uses present in California. These models incorporate satellite retrievals of vegetation index and land cover and are currently used in the NASA Carbon Monitoring System Flux Product. Data products resulting from the proposed work include optimized CO2 flux distributions and totals, including uncertainty, for the State of California for both fossil fuel emissions and biospheric exchange, providing an atmospheric observation-based MRV product that can be used to support California's AB-32 policy. The prototype system we develop could be replicated in other regions, providing similar MRV applications to other greenhouse gas emission policies.

Keywords:

Project Associations:

- NASA CMS

Spatial Extents of Study:

- US

CMS:

- Land-Atmosphere Flux
- MRV

Participants:

Marc Fischer, Lawrence Berkley National Laboratory
Heather Graven, Scripps Institution of Oceanography
Ralph Keeling, UCSD Scripps Institution of Oceanography
Nick Parazoo, UCLA

Project URL(s): None provided.

Research Contributions:

Contribution	**Available by:**
Product Title: Fossil fuel and biospheric CO2 fluxes for California	

Description:

- **Objective:** Pilot project to observe spatial patterns of fossil fuel-derived and biospheric CO2 in California by field sampling and measurement of radiocarbon in CO2 from a network of tower sites, use radiocarbon observations with in situ and satellite CO2 measurements in regional CO2 inversion, quantify uncertainties, and compare with bottom-up inventories
- **Inputs/Data products used:** Radiocarbon data, total CO2 data from towers and OCO-2, CMS Flux Products
- **Algorithm/Name of models used:** WRF-STILT, CMS Flux Products
- **Spatial Domain:** California
- **Time Period:** May and Nov. 2014
- **Evaluation:**
- **Intercomparison efforts/gaps:**
- **Uncertainty estimates:** Model-data comparison of PBL and wind, back-trajectory ensembles,

use of alternate prior models, pseudo-data analysis, data reproducibility

- **Uncertainty categories:** All: ensemble; deterministic; model-data comparison; model-model comparison; data-data comparison

Expected Users:
Metadata URL(s):
Data Server URL(s):

Publications: None provided.

Hagen-01 (2013)

Project Title: Operational multi-sensor design for national scale forest carbon monitoring to support REDD+ MRV systems

Science Team Members: Stephen (Steve) Hagen, Applied Geosolutions (**Project Lead**)

Abstract: Parties to the United Nations Framework Convention on Climate Change (UNFCCC) have been requested to establish robust and transparent national forest monitoring systems (NFMS) that use a combination of remote sensing and ground-based forest carbon inventory approaches to estimate anthropogenic forest-related greenhouse gas emissions and removals, reducing uncertainties as far as possible. A country's NFMS should also be used for data collection to inform the assessment of national or subnational forest reference emission levels and/or forest reference levels (RELs/RLs). In this way, the NFMS forms the link between historical assessments and current/future assessments, enabling consistency in the data and information to support the implementation of REDD+ activities in countries. The creation of a reliable, transparent, and comprehensive NFMS is currently limited by a dearth of relevant data that are accurate, low-cost, and spatially resolved at subnational scales. We propose to develop, evaluate, and validate several critical components of a NFMS in Kalimantan, Indonesia, focusing on the use of LiDAR and radar imagery for improved carbon stock and forest degradation information. Our goal will be to evaluate sensor and platform tradeoffs systematically against in situ investments, as well as provide detailed tracking and characterization of uncertainty in a cost-benefit framework. Kalimantan is an ideal area to evaluate the use of remote sensing methods because measuring forest carbon stocks and their human caused changes with a high degree of certainty in areas of dense tropical forests has proven to be difficult. While the proposed NFMS components will be developed at the subnational scale for Kalimantan, we will target these methods for applicability across broader geographies and for implementation at various scales. This proposed research will advance the state of the art of Measuring, Reporting, and Verification (MRV) system methodologies in ways that are both technical and operational. First, because a primary focus of carbon monitoring systems, especially in developing countries, is on cost-effectiveness, our analysis of optimal inputs of information from various satellite, airborne, and in situ measurements will provide valuable practical information that countries can use to consider the tradeoffs. Second, because quantifying and understanding uncertainty is critical both in an Earth science research context and with regard to payment for ecosystem services, our development of reusable methods for tracking and evaluating uncertainty within a carbon monitoring system will provide a framework for stakeholders and researchers to understand and minimize errors across MRV components. Third, because carbon monitoring requires integration of advanced technologies with multidisciplinary scientific methods from forestry, ecology, soil science, remote sensing and biogeochemistry, our team's expertise is particularly well-constructed to address these complex scientific and technical issues.

Keywords:

Project Associations:

- NASA CMS

Spatial Extents of Study:

- US

CMS:

- Land Biomass
- MRV

Participants: Stephen (Steve) Hagen, Applied Geosolutions

Project URL(s): None provided.

Research Contributions:

Contribution	Available by:
Product Title: Kalimantan forest carbon stock and flux maps for 2010-2015; uncertainty tracking system	
Description: • **Objective:** Develop critical components of a Nation Forest Monitoring System in Kalimantan, Indonesia by 1) Developing an uncertainty trackingsystem for carbon monitoring; 2)Mapping carbon emissions associated with degradation using LiDAR and radar; 3) Producing improved wall-to-wall forest carbon stock maps using LiDAR, radar, and optical data. • **Inputs/Data products used:** Field measurements of forest structure/biomass,Airborne LiDAR, PALSAR, Landsat/MOIDS • **Algorithm/Name of models used:** • **Spatial Domain:** Kalimantan, Indonesia • **Time Period:** 2010-2015 • **Evaluation:** • **Intercomparison efforts/gaps:** • **Uncertainty estimates:** One primary objective is to develop usable tools to assist the process of tracking uncertainty from ground estimates of forest biomass through modeling and remote sensing, up to wall-to-wall maps. • **Uncertainty categories:** ensemble; model-data comparison	
Expected Users:	
Metadata URL(s):	
Data Server URL(s):	

Publications: None provided.

Keller-01 (2013)

Project Title: A data assimilation approach to quantify uncertainty for estimates of biomass stocks and changes in Amazon forests

Science Team Members: Paul Duffy, Neptune Inc.
Michael Keller, USDA Forest Service (**Project Lead**)

Abstract: Brazilian tropical forests contain approximately one-third of the global carbon stock in above-ground tropical forest biomass. Deforestation has cleared about 15% of the extensive forest on the Brazilian Amazon frontier. Logging, and understory forest fires may have degraded a similar area of forest. In response to the potential climatic effects of deforestation, policy makers have suggested reductions in emissions through deforestation and forest degradation and enhanced forest carbon stocks (REDD+). Carbon accounting for REDD+ requires knowledge of deforestation, degradation, and associated changes in forest carbon stocks. Degradation is more difficult to detect than deforestation so SilvaCarbon, an US inter-agency effort, has set a priority to better characterize forest degradation effects on carbon loss. We propose to quantify carbon stocks and changes and associated uncertainties in Paragominas, a jurisdiction in the eastern Brazilian Amazon with a high proportion of logged and burned degraded forests where political change has opened the way for REDD+. We will build on a long history of research including our extensive studies of logging damage. In addition, we will use recent forest inventories and airborne lidar supported by USAID and managed by the US Forest Service and the Brazilian Corporation for Agricultural Research (EMBRAPA) under the Sustainable Landscapes Brazil program. Existing data will allow us to start analysis immediately and will also permit REDD+ relevant multi-temporal measurements of change during the brief three-year study period. We plan to supplement the existing data by collection of additional ground-based forest inventory data contemporary with commercial airborne lidar (supported by USAID) and Landsat remote sensing data that will incorporate a novel use of time series data to estimate the structural properties of degraded forests using bidirectional reflectance information. We identify two objectives for forest carbon accounting at the jurisdictional level: - Quantify spatially explicit above-ground carbon stocks and the changes in carbon stocks; - Quantify spatially explicit uncertainties in above-ground carbon stocks and changes in carbon stocks We will meet these objectives by employing innovative data assimilation methods. Our approach employs a hierarchical Bayesian modeling (HBM) framework where the assimilation of information from multiple sources is accomplished using a change of support (COS) technique. The COS problem formulation allows data from several spatial resolutions to be assimilated into an intermediate resolution. This approach provides a mechanism to assimilate information from multiple sources to produce spatially-explicit maps of carbon stocks and changes with corresponding spatially explicit maps of uncertainty. Importantly, this approach also provides a mechanism that can be used to assess the value of information from specific data products. Hence future data collection can be optimized in the context of the reduction of uncertainty. The spatially explicit quantification of uncertainties naturally provides insights into effective sampling designs. Members of the team used this statistical approach previously as part of prototyping efforts for the National Ecological Observatory Network. The proposed work will add a new research dimension to the Sustainable Landscapes Brazil program, a direct outcome of the US-Brazil Memorandum of Understanding on climate change. Through that program, we have already successfully acquired airborne remote sensing data in Brazil and all requirements for international data collection have already been met. Because the proposed research is closely linked to an active program of international cooperation and capacity building, we will be in a unique position to transfer the results of our research to practitioners in the Brazilian government and in Brazilian civil society.

Keywords:

Measurement Approaches:

- Remote Sensing
- Modeling
- Synthesis

Science Questions:

- Diagnosis

GHG Compounds:

- Carbon Dioxide

Project Associations:

- NASA CMS

Spatial Extents of Study:

- Region
- US

CMS:

- Land Biomass
- MRV

Participants: Paul Duffy, Neptune Inc.
Michael Keller, USDA Forest Service
Douglas (Doug) Morton, NASA GSFC
David Schimel, Jet Propulsion Laboratory
Carlos Souza, IMAZON

Project URL(s): None provided.

Research Contributions: None provided.

Publications: None provided.

Kellndorfer-03 (2013)

Project Title: Time Series Fusion of Optical and Radar Imagery for Improved Monitoring of Activity Data, and Uncertainty Analysis of Emission Factors for Estimation of Forest Carbon Flux

Science Team Members: Josef Kellndorfer, Woods Hole Research Center (**Project Lead**)
Pontus Olofsson, Boston University

Abstract: We propose to support the development and improvement of national MRV systems for REDD+ through two objectives. First, we will develop, test, and share with the public domain robust and transparent methods for mapping activity data (e.g., deforestation, forest degradation). Second, we will conduct an uncertainty analysis of carbon emission estimates from the activity data and from emission factors. We will use novel approaches to time series data mining of optical and radar satellite imagery and conduct the work in three test sites (Colombia, Peru and Mexico) identified as National Demonstrator sites by the Group on Earth Observation's (GEO) Forest Carbon Tracking Task (GEO-FCT). The test sites include a variety of ecosystems, biomass regimes, and cloud-cover conditions, and they exhibit a range of drivers of deforestation and land conversion methods, including selective logging, burning, clearing for permanent conversion, and forest regrowth. A large amount of data from optical and radar satellites has already been collected for these GEO-FCT verification sites. More specifically, we will develop an algorithm from optical and radar time series fusion to produce an accurate assessment of annual changes in areas experiencing deforestation, forest degradation, and forest regrowth (i.e., activity data). The work will include an approach for distinguishing between natural disturbances and permanent anthropogenic change. We will assess the uncertainty and accuracy of the activity data estimated with this algorithm. To assess the uncertainty of carbon emission estimates, we propose to compile a database of country specific emission factors, stratified by land-cover categories (from the first objective), and linked with carbon density estimates from forest inventory and existing biomass maps. The database will contain uncertainty estimates. To provide guidance for national MRV implementation, we will also explore the impact of uncertainties in activity data and emissions factors on carbon fluxes estimated using a bookkeeping model. The proposed work is relevant to the specific objectives of this NASA Carbon Monitoring System solicitation, including rigorous exploitation of NASA and international partner satellite remote sensing resources and computational capabilities. The Subsidiary Body of Scientific and Technological Advice (SBSTA) of the UNFCCC agreed in June 2013 that continuous improvement of data and methods is vital for developing MRV systems for REDD+. In particular, SBSTA identified the need to reduce uncertainties in emissions accounting and to develop methodologically consistent ways to harness new observational data, whether field or remote sensing, that can be used to report against reference levels of deforestation and forest degradation, as well as associated reference emission levels (SBSTA, 2013). To develop methodologically consistent, transparent, yet flexible accounting methods, as required in the international framework of the UNFCCC, as well as numerous bi- and multi-lateral agreements, the Group on Earth Observation (GEO) has established a Forest Carbon Tracking Task (GEO- FCT). PI Kellndorfer and Co-I's Woodcock and Olofsson are among those chosen by GEO to formulate and support the implementation of a Global Forest Observing Initiative (http://geo- fct.org). Support of this proposal would allow them to carry out that work.

Keywords:

Project Associations:

- NASA CMS

Spatial Extents of Study:

- US

CMS:

- Land Biomass
- Land-Atmosphere Flux
- MRV

Participants: Josef Kellndorfer, Woods Hole Research Center
Pontus Olofsson, Boston University

Project URL(s): None provided.

Research Contributions: None provided.

Publications: None provided.

Lauvaux-01 (2013)

Project Title: Quantification of the sensitivity of NASA CMS Flux inversions to uncertainty in atmospheric transport

Science Team Members: Thomas Lauvaux, Pennsylvania State University (**Project Lead**)

Abstract: Uncertainty in atmospheric transport and a lack of atmospheric carbon dioxide (CO2) observations are the two major sources of uncertainty in inverse estimates of CO2 sources and sinks. Space-based measurements of atmospheric CO2 will greatly increase the density of atmospheric measurements. Atmospheric transport, however, remains a major challenge. We propose to improve our understanding of the uncertainties associated with atmospheric transport in the NASA Carbon Monitoring System Flux estimation and attribution pilot project (CMS Flux). This project will focus on uncertainties at the regional to continental scale, focusing in particular on North America for calendar year 2010. The results should be applicable to any mid-latitude continental region. We will: 1) assess the transport error in the global NASA CMS-Flux system and the mesoscale WRF-LPDM using meteorological data and CO2 profiles from airborne measurements over North America; 2) represent transport error with a physics-based ensemble of atmospheric transport configurations; and 3) estimate the contribution of transport uncertainty over North America to North American and global flux uncertainty. This proposal will address the request in the NASA CMS announcement of opportunity for, 'Studies to improve the characterization and quantification of errors and uncertainties in existing and/or proposed NASA CMS products, including errors and uncertainties in the algorithms, models, and associated methodologies utilized in creating them.' We will evaluate the impact of atmospheric transport on the CMS Flux pilot products by embedding the Penn State regional atmospheric inversion system, which utilizes the mesoscale Weather Research and Forecast model (WRF), within the CMS Flux system, by simulating atmospheric CO2 and solving for continental fluxes with both systems, and by evaluating transport uncertainty by comparing the CMS Flux system output to meteorological observations and aircraft CO2 profile data. The first objective will be met by simulating the atmospheric distribution of CO2 across North America with both WRF and Geos-Chem (the CMS Flux atmospheric transport scheme). Both simulations will use the same lateral boundary conditions and surface fluxes. Meteorological observations will be used to quantify the atmospheric transport uncertainty in CMS Flux. Aircraft CO2 profiles will be used to quantify the model-data mismatch error used in CMS Flux inversions. The second objective will be met by running a physics-based ensemble of WRF simulations conditioned to match the range of transport errors found in the CMS Flux system by comparison to meteorological observations. This ensemble will be sampled to simulated GOSAT and OCO-2 observational patterns. This produces a set of column CO2 pseudo-data with a distribution similar to the CMS Flux transport error. The third objective will be addressed by using this ensemble of simulated satellite observations to infer an ensemble of fluxes using the CMS Flux system. The differences among the inferred fluxes should be a realistic representation of atmospheric transport error in the CMS Flux biogenic flux product.

Keywords:

Project Associations:

- NASA CMS

Spatial Extents of Study:

- US

CMS:

- Atmospheric Transport
- Land-Atmosphere Flux

Participants: Thomas Lauvaux, Pennsylvania State University

Project URL(s): None provided.

Research Contributions: None provided.

Publications: None provided.

Nehrkorn-01 (2013)

Project Title: Prototype Monitoring, Reporting and Verification System for the Regional Scale: The Boston-DC Corridor

Science Team Members:
Janusz Eluszkiewicz, Atmospheric and Environmental Research
Lucy Hutyra, Boston University
Charles (Chip) Miller, NASA JPL
Thomas Nehrkorn, AER, Inc (**Project Lead**)
Crystal Schaaf, University of Massachusetts Boston
Steven (Steve) Wofsy, Harvard University

Abstract: The world's population growth is increasingly concentrated in urban areas and this trend is expected to continue in the future. Urbanization has a profound impact on carbon dynamics, leading to increases in anthropogenic carbon dioxide (CO2) emissions and decreases in biogenic fluxes from these areas. The latter are a key component of a carbon monitoring system (CMS), while spatially and temporally resolved estimates of anthropogenic fluxes are central to meeting greenhouse gas emissions reductions goals. We intend to design a measurement network and develop an accompanying atmospheric modeling framework for downscaling the current NASA CMS flux products to the regional and local scales pertinent to Monitoring, Reporting, and Verification (MRV). Our proposed research will focus on the Boston-DC megalopolis corridor, where about 17% of the U.S. population lives on less than 2% of the nation's land area, making it a key source of US anthropogenic CO2 emissions. Simultaneously, these urban areas are interspersed with vegetation that imposes a strong biogenic signal on the atmospheric CO2 mixing ratios. The proposed research will proceed along three main lines: 1) High-resolution transport modeling (WRF-STILT) customized and verified for the region, 2) High-resolution CO2 flux model incorporating anthropogenic emissions estimates and the CASA model (including its 0.5-deg resolution variant that provides the foundational biosphere model for the current CMS Flux Product and nested higher resolution runs to represent the scale sensitivity within heterogeneous urban areas), and 3) Inverse CO2 flux estimates corresponding to in-situ and remote CO2 observations in and around Boston, New York City, and Washington DC. As part of the proposed work, we will quantify errors in the WRF-STILT simulations of the planetary boundary layer (PBL), relying for this purpose on remotely sensed PBL measurements by the Sigma Space Corporation's Micro Pulse LiDAR (MPL). The PBL height is a key parameter entering inverse flux estimates, as it determines the mixing region and varies inversely to the trace gas concentrations. A key result of the proposed research will be the quantification of observing requirements for flux uncertainty reduction to levels needed for MRV. Our proposal addresses two stated goals of the NNH13ZDA001N-CMS solicitation: 'studies using commercial off-the-shelf technologies to produce and evaluate prototype MRV system approaches' and 'studies to improve the characterization and quantification of errors and uncertainties in existing and/or proposed NASA CMS products, including errors and uncertainties in the algorithms, models, and associated methodologies utilized in creating them.' The proposed work will leverage and extend the current CMS projects led by Drs. Arlyn Andrews and Steven Pawson, with which

the lead proposing team at Atmospheric and Environmental Research (AER) is intimately involved, and the CMS pilot surface carbon fluxes modeling analysis.

Keywords:

Project Associations:

- NASA CMS

Spatial Extents of Study:

- US

CMS:

- Atmospheric Transport
- Land-Atmosphere Flux
- MRV

Participants:

Janusz Eluszkiewicz, Atmospheric and Environmental Research
Lucy Hutyra, Boston University
Charles (Chip) Miller, NASA JPL
Thomas Nehrkorn, AER, Inc
Crystal Schaaf, University of Massachusetts Boston
Steven (Steve) Wofsy, Harvard University

Project URL(s): None provided.

Research Contributions:

Contribution	Available by:
Product Title: All measurements collected during the three-year period of the proposed project (and up to one year of historic data) and modeling output (e.g., WRF and STILT output, surface fluxes) will be made publicly available as soon as they have been calibrated, checked, and quality-controlled.	

Description:

- **Objective:** We intend to design a measurement network and develop an accompanying atmospheric modeling framework for downscaling the current NASA CMS flux products to the regional and local scales pertinent to Monitoring, Reporting, and Verification (MRV). Our proposed research will focus on the Boston-DC megalopolis corridor, where about 17% of the U.S. population lives on less than 2% of the nation's land area, making it a key source of US anthropogenic CO2 emissions.The proposed research will proceed along three main lines: 1) High-resolution transport modeling (WRF-STILT) customized and verified for the region, 2) High-resolution CO2 flux model incorporating anthropogenic emissions estimates and the CASA model (including its 0.5-deg resolution variant that provides the foundational biosphere model for the current CMS Flux Product and nested higher resolution runs to represent the scale sensitivity within heterogeneous urban areas), and 3) Inverse CO2 flux estimates corresponding to in-situ and remote CO2 observations in and around Boston, New York City, and Washington DC.
- **Inputs/Data products used:** Meteorological analyses and ancillary data used as IC/BC for WRF; in-situ and remote CO2 observations along the Boston to Washington DC corridor; Mini MPL measurements at 3 locations in the corridor; a priori anthropogenic and biospheric flux estimates and related data, including CASA, Vulcan, HPMS
- **Algorithm/Name of models used:** WRF-STILT transport model; CASA-GFED biosphere model; Bayesian and geo-statistical inversion for posterior flux estimate
- **Spatial Domain:** Boston to DC urban corridor
- **Time Period:**

- **Evaluation:**
- **Intercomparison efforts/gaps:** Posterior flux estimates will be compared against available CMS flux products
- **Uncertainty estimates:** With regard to a priori information, we will rely primarily on model inter-comparisons conducted under diverse community initiatives. In quantifying transport uncertainties, we will begin by verification of atmospheric fields, particularly winds and PBL heights, against observations. We will comprehensively evaluate our WRF runs by computing performance statistics using the WRF-Model Evaluation Tools (WRF- MET; hereafter, MET) software package. We will first focus on a qualitative comparison of the diurnal PBL cycle in WRF with the Mini MPL measurements and then use the latter in a quantitative evaluation of the WRF PBL simulations.We will quality control observing periods, particularly those when the WRF PBL simulation diverges from the Mini MPL measurements. We will then compare inversions with or without this quality control step, to help quantify the impact of PBL height uncertainties on the fluxes. Uncertainties of posterior flux estimates will be based on posterior covariance estimates from inversion.
- **Uncertainty categories:** 2. deterministic and 3. model-data comparison

Expected Users:
Metadata URL(s):
Data Server URL(s):

Publications: None provided.

Nelson-03 (2013)

Project Title: A Joint USFS-NASA Pilot Project to Estimate Forest Carbon Stocks in Interior Alaska by Integrating Field, Airborne and Satellite Data

Science Team Members:
Bruce Cook, NASA GSFC
Douglas (Doug) Morton, NASA GSFC
Ross Nelson, NASA GSFC (**Project Lead**)

Abstract: Monitoring U.S. forest carbon stocks is critical for natural resource management and national greenhouse gas reporting activities. The USFS Forest Inventory and Analysis (FIA) program 'the largest network of permanent forest inventory plots in the world' covers most U.S. forestlands. However, more than 450,000 km2 of forests in interior Alaska (15% of US forestland) are not included in the FIA program, as these remote regions are difficult and expensive to monitor with standard field methods. Recent and projected future impacts from climate change on forest carbon stocks, composition, and extent have elevated the need to develop new approaches for forest monitoring in Alaska. In particular, airborne remote sensing offers unique advantages for monitoring remote forested regions. In many respects, the methods, logistics, and timeliness of carbon monitoring in Alaska are analogous to ongoing efforts to develop carbon monitoring systems for remote tropical forest regions to Reduce Emissions from Deforestation and forest Degradation and enhancing forest carbon stocks (REDD+). Here, we propose to develop the first regional estimates of forest carbon stocks for the Tanana Inventory Unit of interior Alaska (146,000 km2). The proposed research leverages a sizable investment ($800k) by the USFS FIA Program in 2014 for new forest inventory plots and airborne data collection with Goddard's LiDAR, Hyperspectral, and Thermal Airborne Imager (G-LiHT; http://gliht.gsfc.nasa.gov). G LiHT is a well-calibrated airborne remote sensing package that is assembled from commercial off-the-shelf (COTS) instruments and a proven track record of timely, free, and open access to both low-and high-level products. The USFS project, a pilot study for LiDAR-assisted forest inventory in interior Alaska, does not provide support for research collaboration between NASA and USFS scientists, data analysis, or methods development. In this project, we will expand the Tanana research

activity to 1) collaborate on the experimental design for optimal integration of field and LiDAR data for forest carbon monitoring; 2) compare established model-based and model-assisted methods for estimating forest carbon stocks using both plot and LiDAR information; 3) enhance the inventory activity using individual tree, species composition, and vegetation cover information from the combination of G-LiHT hyperspectral, thermal, and LiDAR sensors; and 4) characterize the impacts of recent fires and risk of future fire-driven carbon losses using the systematic sample of G-LiHT flight lines over ~2.5% of the Tanana region (3800 km2); and 5) develop new, spatially explicit estimates of carbon stocks and uncertainties using Bayesian statistical methods. The main outcomes from this work will be estimates of forest carbon stocks and associated uncertainties for the Tanana Inventory Unit. These estimates provide critical and timely information for resource management, and baseline conditions for the spatial distribution of forest cover and carbon stocks in a region that is rapidly changing from climate warming.

Keywords:

Project Associations:

- NASA CMS

Spatial Extents of Study:

- US

CMS:

- Land Biomass
- MRV

Participants:

Hans Andersen, USDA Forest Service, Pacific Northwest Research Station
Bruce Cook, NASA GSFC
Andrew (Andy) Finley, Michigan State University
Douglas (Doug) Morton, NASA GSFC
Ross Nelson, NASA GSFC
Robert Pattison, USDA Forest Service, Anchorage Forestry Sciences Laboratory

Project URL(s): None provided.

Research Contributions: None provided.

Publications: None provided.

Stehman-01 (2013)

Project Title: Developing Statistically Rigorous Sampling Design and Analysis Methods to Reduce and Quantify Uncertainties Associated with Carbon Monitoring Systems

Science Team Members: Stephen (Steve) Stehman, SUNY College of Environ Sci & Forestry (**Project Lead**)

Abstract:

The research described in this proposal will develop statistically rigorous sampling design and analysis protocols that will reduce uncertainty of key estimates of target parameters of a carbon monitoring system (CMS) and lead to better quantification of uncertainty. The IPCC Good Practice Guidance emphasizes the importance of land area to estimates of carbon stocks and emissions and removals of greenhouse gases associated with land use, land-use change and forestry activities. Effective regional, national and global carbon monitoring systems can exploit satellite remote sensing in a variety of ways to substantially reduce the uncertainty of area estimates and to reduce costs associated with field sampling. A central theme of the proposed research is to develop and evaluate methods for advantageously combining remote sensing and ground data obtained from multiple sources to obtain more accurate (i.e., unbiased) and more precise estimates of land area and other key parameters of a CMS. Sampling is a key component of a CMS because much of the information needed for monitoring can only be collected in a cost-effective way via a sample. The proposed research is heavily focused on sampling methods. The outcome of the research will be recommendations for choosing a sampling design and estimation protocol that effectively combines information from multiple data sources emphasizing airborne and satellite remote sensing and field plot data. The specific objectives addressed include: 1) identify effective sampling designs and estimators that take

advantage of remote sensing information to reduce costs and uncertainty associated with sample-based estimates; 2) compare different sample-based estimators proposed for a commonly used design in monitoring (two-stage cluster sampling) and provide a recommendation for which estimator(s) most effectively use remote sensing information to reduce uncertainty; 3) develop methods for quantifying measurement error (in particular, reference data error associated with assessing accuracy of land cover and land change maps) and for estimating land cover or land change area taking into account this measurement error; 4) develop rigorous sampling design and estimation protocols for incorporating community based monitoring and volunteered geographic information into land change monitoring protocols; and 5) investigate approaches for combining information from two probability samples to improve precision of estimates. Two obvious desirable goals for designing a CMS are to reduce uncertainties and lower costs. This research will achieve both of these benefits because the results of the research will guide selection of a cost effective sampling design and use of statistical estimators that take advantage of combining airborne and satellite remote sensing to reduce variability of key sample-based estimates required of the CMS. The proposed work not only contributes to a more efficient and effective CMS but also contributes to the wider NASA mission of validating land cover and land change products.

Keywords:

Project Associations:

- NASA CMS

Spatial Extents of Study:

- US

CMS:

- Land Biomass
- MRV

Participants: Stephen (Steve) Stehman, SUNY College of Environ Sci & Forestry

Project URL(s): None provided.

Research Contributions: None provided.

Publications: None provided.

Vargas-01 (2013)

Project Title: A framework for carbon monitoring and upscaling in forests across Mexico to support implementation of REDD+

Science Team Members: Richard Birdsey, USDA Forest Service
Kristofer (Kris) Johnson, USDA Forest Service
Rodrigo Vargas, University of Delaware (**Project Lead**)

Abstract: Rationale: Mexico is a mega-diverse country where nearly 40% of its territory is covered by forests. The long-term impacts of land use and anthropogenic changes have fragmented and fundamentally transformed Mexican landscapes. Therefore, forests in Mexico are determined by climate gradients and land history creating a heterogeneous landscape. The most important land use change types having caused severe ecological degradation include: deforestation, high impact livestock grazing, and soil tillage. Furthermore, Mexico has shown an average rate of deforestation of nearly 550,000 ha year for the period 1993-2007 with a slight increase in natural forest regeneration, particularly in southern Mexico. It is estimated that gross primary productivity (GPP) of the conterminous USA is ~7 PgC, but Mexico's ecosystems uptake ~2.6 PgC yr-1 with only 1/3 of the USA land mass. During the last decade the scientific capacity of Mexican scientists has rapidly increased and state-of-the-art measurements on carbon dynamics are now available at representative landscapes, and nationally supported by remote sensing and a national forest inventory. Thus, the time is ripe to test different approaches towards a framework for monitoring, reporting and verification (MRV) to support implementation of REDD+ across a gradient of forests in Mexico. Overall goal: to analyze carbon stocks and dynamics from ecosystem- to the regional-scale as well as characterize and quantify the errors and uncertainties across scales for the MRV to support implementation of REDD+ in

Mexican forests. Specific objectives: 1) standardize ongoing methodologies for upscaling forest inventories and carbon dynamics measurements across 6 intensive forest monitoring sites; 2) characterize and quantify the errors and uncertainties in measurements and ecosystem models (BESS, DNDC) and remote sensing approaches (MODIS) for upscaling purposes of carbon dynamics in Mexican Forests; 3) identify hot-spots suitable for REDD+ and assess the potential vulnerability and variability of carbon dynamics at the national scale for the last 13 years. Approach: this proposal builds upon ongoing efforts by the USDA Forest Service (support by USAID and the Commission for Environmental Cooperation) and the University of Delaware to study carbon dynamics in ecosystems across Mexico. This proposal will consolidate collaboration with Mexican scientists across six intensive forest monitoring sites (Tier 3) representing different forest types (evergreen, deciduous, mix, mangrove). Detailed data, including forest inventory, LIDAR, and net ecosystem exchange (NEE; using the eddy covariance technique) is already available at most sites. First, this proposal will standardize/harmonize the available data across sites (forest inventory, eddy covariance). Second, we will validate biomass, NEE, and gross primary productivity (GPP) at the site level based on forest inventories and eddy covariance measurements with ecosystem models (BESS, DNDC), and remote sensing approaches (MODIS). Third, errors and uncertainties will be quantified at the ecosystem-level and at the regional scale for estimation of carbon socks and carbon dynamics across Mexican forests. Finally, we will use 13 years of archived remote sensing information (MODIS 2000-2013) to identify hot-spots, extreme values and trends at the regional scale that will provide insights for establishment for REDD+ initiatives. Significance: This proposal supports NASA carbon cycle research through validation of MODIS products through measurements of forest inventories, and cross-validation with other models. This study will generate harmonized datasets on carbon cycle science in Mexico to make them comparable to datasets available in the United States.

Keywords:

Project Associations:

- NASA CMS

Spatial Extents of Study:

- Mexico
- US

CMS:

- Land Biomass
- MRV

Participants: Richard Birdsey, USDA Forest Service
Kristofer (Kris) Johnson, USDA Forest Service
Rodrigo Vargas, University of Delaware

Project URL(s): None provided.

Research Contributions: None provided.

Publications: None provided.

West-04 (2013)

Project Title: Carbon Monitoring of Agricultural Lands: Developing a Globally Consistent Estimate of Carbon Stocks and Fluxes

Science Team Members: Tristram (Tris) West, Joint Global Change Research Institute (**Project Lead**)

Abstract: A comprehensive carbon monitoring system will likely include the integration of bottom-up and top-down estimates. Current bottom-up estimates for global agricultural lands often consist of individual inventory-based estimates per country. This results in a global bottom-up estimate that is not consistent in underlying soils or land cover data, methods of estimating carbon stocks and fluxes, or estimates of uncertainty. The proposed research will use off-the-shelf data, models, and remote sensing products to develop a global bottom-up, inventory-based estimate of carbon stocks and fluxes for agricultural lands,

including vegetation and soils. The annual estimates will be generated using globally consistent datasets, C estimation methods, and methods for estimating uncertainty. Land area will be defined by a fusion of MODIS land cover data and inventory-based land area data. Methods will coincide with current national and international methods and protocols for compatibility with ongoing efforts in carbon monitoring, reporting, and verification. While these estimates can be used independently for synthesis and assessment reports, they can also be (a) used in conjunction with similar global data on forest carbon stocks and fluxes, thereby generating one comprehensive bottom-up, inventory-based estimates, and (b) used to evaluate the latest state-of-the-art monitoring components generated by NASA in the coming years. A scoping study will also be conducted to determine how the bottom-up, inventory-based estimate can be improved upon or integrated with other satellite-based bottom-up estimates, and how the global agricultural estimate can be integrated with previously conducted estimates on global forest carbon.

Keywords:

Project Associations:

- NASA CMS

Spatial Extents of Study:

- US

CMS:

- Land Biomass
- Land-Atmosphere Flux
- Decision Support

Participants: Tristram (Tris) West, Joint Global Change Research Institute

Project URL(s): None provided.

Research Contributions: None provided.

Publications: None provided.